INTERRELATIONSHIPS BETWEEN LATE LEAFSPOT DISEASE AND FLORUNNER PEANUT: A MODELING APPROACH

BY

GAETAN BOURGEOIS

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To my wife, Johanne

for making this achievement possible

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by

Gaétan Bourgeois

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Late leafspot, induced by *Cercosporidium personatum* (Berk. & Curt.) Deighton, is the most important foliar disease affecting peanut (*Arachis hypogaea* L.) in Florida and neighboring states. The disease first occurs as necrotic lesions on peanut leaflets and subsequently induces leaflet abscission. Field experiments and model simulations were conducted to study effects of late leafspot on peanut growth and photosynthesis. Leaflet photosynthesis was reduced linearly with the increase in the necrotic leaf area. Reduction in light interception by necrotic lesions did not explain completely the reduction in leaflet photosynthesis. At the canopy level, the effect of reduction in leaflet photosynthesis was negligible compared to the effect of disease-induced defoliation. Canopy photosynthesis was inversely proportional to the disease severity, which is an expression of both defoliation and necrotic area. Florunner peanut defoliated completely when the crop was not protected with fungicides, and pod losses increased rapidly after complete defoliation.

Interactions between late leafspot, the peanut plant, and the environment were studied with simulation models. A simulation model of the progression of late leafspot (LATESPOT) on Florunner peanut was developed and coupled to PNUTGRO, a growth simulator of peanut. LATESPOT includes functions for dissemination of conidia, infection of leaf tissues by the conidia, disease development in the leaf which includes expansion of infected leaf area, colonization, sporulation, and spore release from infectious lesions. All these processes are affected by daily environmental conditions. The effect of late leafspot on peanut was simulated by reducing canopy photosynthesis due to disease-induced defoliation, and by reducing light interception due to the presence of necrotic lesions on attached leaves. The coupled model, PNUTGRO-LATESPOT, was calibrated with field data collected during 1986, and was validated with field data collected during 1983, 1985, and 1987. The four years represented a range of planting dates and locations in Florida. The disease severity and reductions in dry weight of vegetative and reproductive organs were predicted adequately by the PNUTGRO-LATESPOT model. In sensitivity analyses of the LATESPOT model, the parameters related to the development of the pathogen in the leaf caused the most variation in the disease severity.

CHAPTER 1

INTRODUCTION

Peanut, *Arachis hypogaea* L., is grown on over 18 million ha throughout the world. Leading producers are India, China, Senegal, United States, Nigeria, Burma, Sudan, Indonesia, and Zaire (FAO, 1987). About 600,000 ha are harvested in the United States, and seven states (Georgia, Alabama, North Carolina, Texas, Virginia, Florida, and Oklahoma) account for 98% of the production (USDA, 1987). The peanut plant is a self-pollinated, annual, herbaceous legume. The fertilized flowers produce gynophores, commonly called pegs, which are elongations of the base of the ovary. The pegs develop, elongate quickly, enter the soil, and the pods develop on the terminals of the gynophores beneath the soil surface. The photosynthetic unit of the peanut plant is the tetrafoliate, pinnately compound leaf with two opposite pairs of leaflets.

Models of growth and development of peanut offer considerable potential to assist with transfer of agrotechnology, decision making for crop management, research guidance, and understanding and synthesis of results of past and present research projects. Boote *et al.* (1985b) modified a soybean crop growth model, SOYGRO (Wilkerson *et al.*, 1983; 1985) to develop a peanut growth simulation model, PNUTGRO. PNUTGRO is a physiologically-based crop growth model which is affected by daily weather inputs (temperature, rainfall, radiation, and photoperiod) and includes crop carbon balance and nitrogen balance at the process level.

The direct effect of diseases on the physiological processes of the plant is not included in the PNUTGRO model.

The major foliar diseases of peanut are early leafspot, induced by *Cercospora arachidicola* Hori, and late leafspot, induced by *Cercosporidium personatum* (Berk. & Curt.) Deighton. In some cases, early leafspot is the predominant disease, and in others, late leafspot is predominant. Early and late leafspots are first recognizable as small necrotic flecks that enlarge and become light to dark brown spots ranging from 1 to 10 mm in diameter. Early leafspot usually has a light to dark brown center and a yellow halo. The halo is often less conspicuous or absent with late leafspot lesions. However, positive identification of early and late leafspots requires microscopic examination of the conidia of the causal fungi.

Lesions caused by both fungi also develop on petioles, stipules, stems, and pegs in the later stages of an epidemic (Porter *et al.*, 1982; Smith, 1984). Necrotic lesions caused by *C. arachidicola* are produced by cellulolytic and pectolytic enzymes which degrade constituents of the cell wall and middle lamellae (Alabi and Naqvi, 1977). These enzymes are secreted by intercellular hyphae and kill host cells prior to hyphal penetration (Gibbons, 1966; Jenkins, 1938). *Cercosporidium personatum* does not kill host cells in advance of hyphal penetration and, unlike *C. arachidicola*, produces haustoria within living cells (Jenkins, 1938: Woodroof, 1933). Both *C. arachidicola* and *C. personatum* have been shown to produce the photosensitizing toxin cercosporin *in vitro* and in the leaves of diseased plants (Abo-El-Dahub *et al.*, 1985; Venkataramani, 1967). Cercosporin is a nonspecific toxin that affects cells of some plants only when they are exposed to light (Daub, 1982).

Boote *et al.* (1983) simulated leafspot damage on peanut photosynthesis and yield. They hypothesized that disease effects on photosynthesis were mediated through loss of leaf area by acceleration of senescence, shading of healthy leaf area by leafspots, and a toxic effect of leafspot disease on the photosynthetic mechanism of the remaining leaves. A moderate rate of leafspot development and leaf defoliation due to *Cercospora* spp. was simulated by using a Gompertz function, as defined by Berger (1981). This function was coupled to PNUTGRO. Results obtained from this simulation were reasonable, although the simulations were strickly hypothetical and needed to be tested against growth analyses and leafspot assessment. The simulated Cercospora leafspot disease decreased the leaf area index (LAI), vegetative growth, and reproductive growth.

Various growth equations (logistic, Gompertz, Richards, and Weibull) have been used to characterize the progress of disease over time (Berger, 1981; Freedman and MacKenzie, 1987; Jowett *et al.*, 1974; Madden, 1980; Vanderplank, 1963). However, these simple growth equations lack substantial biological realism as models for disease progress. Several important epidemiological factors are neglected or not characterized (e.g. host growth, length of latent period, variable latency of infections, and lesion expansion). Berger and Jones (1985) presented a general model for disease progress which includes those epidemiological factors. They proposed that their combined model with its numerous mathematical variations can be the initial model to develop an epidemic simulator of any pathosystem. The researcher needs to choose the representative functions and parameters that fit the natural host growth and disease progress. It is also possible, in some simulations with their model, to stop infections in certain time periods to mimic the effect of unfavorable

weather for disease or the application of a control procedure. However, their model is still based on arbitrary growth equations and does not reflect or explain the development of the pathogen and the host at the process level. Furthermore, environmental effects on crop and pathogen components in a given pathosystem needs to be included.

When possible, the use of a disease simulation model coupled to a crop growth simulator would give more insight in the epidemiological system and would be more promising for applications in crop protection. Several simulation models have been published, often under fashionable names such as EPIMAY (Waggoner *et al.*, 1972), EPIMUL (Kampmeijer and Zadoks, 1977), and EPIPRE (Rabbinge and Rijsdijk, 1983). These models are deterministic, but in recent versions, stochastic features have been incorporated. Among them are probability distributions of germination periods and latent periods, and of spore dispersal and spore effectiveness (Zadoks and Schein, 1979). Zadoks (1971) considered the host to consist of a large but finite number of infection sites. The pool of infection sites is increased as the host grows. An infection site is defined as having one of the following mutually exclusive conditions: vacant (void of infections), latent (infected but not symptomatic), infectant (infectious, producing spores), and removed (not participating actively in the epidemic because of age, death, or removal by defoliation and decomposition). The physical dimensions of an infection site roughly coincide with the reproductive unit of the parasite studied. Knudsen *et al.* (1987) used this infection-site approach in their simulation model for Cercospora leafspot of peanut. In their model, each peanut leaflet was considered as one infection site.

The objectives of this research were 1) to determine the effect of late leafspot on the development and growth of Florunner peanut, and on the photosynthetic rate of peanut leaflets and canopies, and 2) to develop a simulation model of the late leafspot disease and peanut pathosystem based on the approach of Zadoks (1971). Calibration, validation, and sensitivity analyses of this simulation model will be presented.

CHAPTER 2

EFFECT OF LATE LEAFSPOT ON FLORUNNER PEANUT GROWTH, DEVELOPMENT, AND SEED QUALITY

Among all foliar diseases affecting peanut (*Arachis hypogaea* L.), early and late leafspot, induced by *Cercospora arachidicola* Hori and *Cercosporidium personatum* (Berk. & Curt.) Deighton, are probably the most common and destructive diseases everywhere peanut is grown. In Florida, late leafspot is the predominant disease in the peanut fields (Jackson, 1981), and it can cause yield losses over 50% if fungicides are not used (Knauft *et al.*, 1986; Pixley, 1985; Shokes *et al.*, 1983; Smith and Littrell, 1980). These losses in yield are first associated with a reduction in leaf area index (LAI) which causes a reduction in light interception (Bell, 1986; Elston *et al.*, 1976; Teare *et al.*, 1984). Backman and Crawford (1984) reported that for the Florunner cultivar with a yield potential of about 4400 kg ha^{-1}, yield was reduced by an average of 57 kg ha^{-1} for each percent of defoliation assessed two weeks before harvest. Canopy photosynthesis is reduced and less photosynthate is available for pod growth. Waggoner and Berger (1987) proposed the concept of healthy leaf area duration (HAD) and healthy area absorption (HAA) to predict the pod yield of a peanut crop affected by Cercospora leafspot. They concluded that yield was simply determined by HAD and was linearly related to HAA whether the crop was defoliated by man or by disease. However they did not consider important yield losses due to the abscission

of pods close to harvest time. When the plants are pulled from the soil, the pegs break and the pods can not be harvested with standard equipment (Boote, 1982; Duke, 1971; Duncan *et al.*, 1978; Knauft *et al.*, 1988; Pixley, 1985; Teare *et al.*, 1984; Thomas *et al.*, 1983; Troeger *et al.*, 1976). Whether or not these losses are induced by both *C. arachidicola* and *C. personatum* is not known.

Early and late leafspot can be first recognized as small necrotic flecks on the leaflets. Each fleck enlarges and becomes a necrotic lesion which is associated with loss of chlorophyll pigments (Melouk, 1978). Differences in symptoms observed with early leafspot and late leafspot have been noted by several workers, but all scientists agree that positive identification can only be obtained by microscopic observation of the conidia (Porter *et al.*, 1982; Smith, 1984). The major effect of leafspot diseases is to increase leaflet abscission which reduces light interception and photosynthesis (Boote *et al.*, 1983; Watson, 1987). The cause of this early defoliation is not really understood. There are some reports of cercosporin production, a photosynthesizing toxin activated by light (Abo-El-Dahab *et al.*, 1985; Daub, 1982; Daub and Hangarter, 1983; Venkataramani, 1967), and increase in ethylene, a growth regulator that induces abscission (Ketring and Melouk, 1982). Additionally, the necrotic lesions themselves represent loss of photosynthetic area even while leaflets have not abscised.

The disease progresses from the lower part to the upper part of the peanut canopy. Plaut and Berger (1980) used a semi-circular template approach to assess the disease effect in three canopy layers: bottom, middle, and top. Both necrotic area and defoliation must be assessed in a disease assessment program. Necrotic area is usually assessed with the

aid of an arbitrary scale, as the Horsfall-Barratt (1945) scale or a pictorial key (Shokes *et al*., 1987). An experienced eye is required in both cases to obtain an accurate estimation. The Horsfall-Barratt scale can also be used to assess percent defoliation, but the most commonly used technique is to count the number of missing leaflets on the main stem (Shokes *et al*., 1987). This system assumes that leaflets are missing due to disease, but this assumption is not absolutely correct. Problems were observed early in the growing season with the latter technique in evaluating defoliation due to natural senescence at the lower nodes of the main stem. Pixley (1985) observed a defoliation percentage of 20% at 50 days after planting (DAP) in the plots treated with fungicides, and Shokes *et al*. (1987) observed defoliation percentage of 10 to 20% in peanut which had excellent disease control and very little disease. Pixley (1985) computed a disease-induced defoliation by subtracting the defoliation estimated in the plots treated with fungicides from the one estimated in the non-treated plots. As a result, only 70% of the total defoliation at 131 DAP was induced by the leafspot disease. Nutter and Alderman (1987) also indicated the overestimation of defoliation with the use of the number of missing leaflets on the main stem technique. They suggested that the number of missing leaflets on the branch stems be counted, which would be more representative of the peanut canopy.

To obtain a quantitative estimate of yield loss from disease severity, accurate assessments for both defoliation and proportion of necrotic area are needed. Furthermore, an extensive estimation of growth and development of the peanut canopy is also important. This experiment was undertaken to improve the understanding of the interrelationships between the late leafspot disease and the peanut canopy. Data obtained

from this experiment was used to develop an evaluate a simulation model for the progression of late leafspot on Florunner peanut.

Materials and Methods

The experiment was conducted at the Agronomy Farm of the University of Florida in Gainesville. Florunner peanut was planted on 2 June during summers of 1986 and 1987 at a rate of 20 seeds m^{-1} in rows 0.91 m apart to achieve a population of 13 to 14 plants m^{-2}. Irrigation with overhead sprinklers provided water to the field when needed (Fig. 2-1). Weeds were controlled with pre-plant and pre-emergence herbicides. Escaped weeds were removed manually after plant emergence. Insecticides were applied as needed to control insects. Gypsum was applied at a rate of 1009 and 1345 kg ha^{-1} in 1986 and 1987, respectively, at the pegging stage which occurred 40 to 42 days after planting (Tables A-1 and A-2).

The experimental design was a completely randomized block with two treatments: 1) fungicide treated and 2) not treated, and four replications. The fungicide chlorothalonil was used at a rate of 2.3 l ha^{-1}. Applications of fungicide began 32 and 23 days after planting in 1986 and 1987, respectively. Time between applications was between 8 and 12 days, and sprays were applied until the first week of October.

Growth Analysis

Starting three weeks after planting, one meter of row in each plot was selected on a bi-weekly basis for measurements and analysis of growth. Percent light interception and absorption were determined using a line quantum sensor (LI-COR LI-191SA). Reproductive and vegetative stages (Boote, 1982) were assessed. The whole meter sample was harvested and the roots discarded. The soil of the harvested area was sieved to find pods

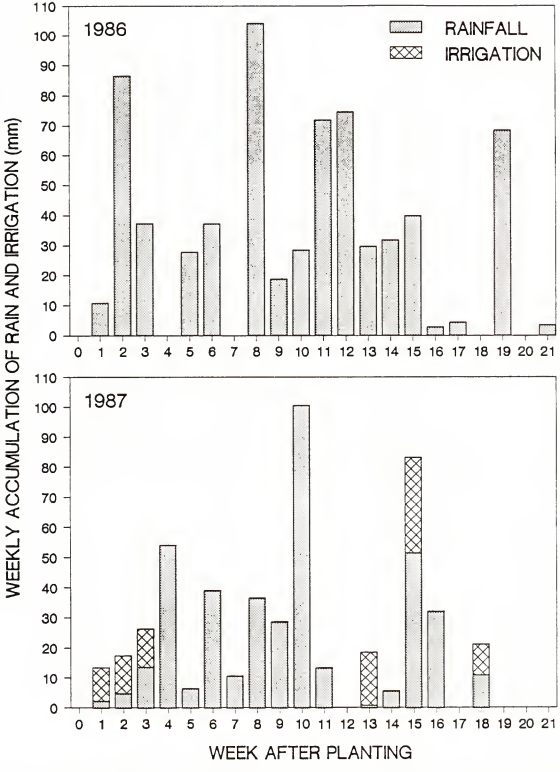


Figure 2-1. Weekly accumulation of rain and irrigation in Gainesville, FL during summers of 1986 and 1987.

left in the soil due to the harvesting procedure or diseases that caused deterioration of the pegs. Pods abscised due to the handling of the plants could be easily distinguished from pods abscised due to diseases causing peg deterioration. With handling, the peg breaks at the attachment site of the pod or the plant stem. With disease, the peg breaks other than at these attachment sites, and the peg shows symptoms of rotting. In the latter case, part of the peg is usually attached to the pod. Pods abscised due to handling were added to the whole biomass sample. An average representative plant was selected in each sample and separated into three plant components: 1) leaf blades, 2) pods, and 3) stems, pegs, petioles, and flowers. The area of the leaves was measured with a leaf area meter (LI-COR LI-3100). All samples were dried at 60°C until no changes in weight were observed, and the weight of dry matter was determined. Pods were subdivided into immature (shrunk after drying) and mature pods, and the number in each class was determined. Mature pods were opened to recover the seeds. Seed weight and number were also obtained.

Disease Assessment

Late leafspot disease was assessed on each selected plant from the field sample. Defoliation was assessed by counting the number of missing leaflets on the main stem. This estimation was further corrected for defoliation due to natural senescence at the lower nodes of the main stem. The defoliation due to disease (d_t) was estimated with the following equation:

$$d_t = m_d / (f_t - \bar{m}_s) \qquad (m_d \geq 0)$$

$$\text{where } m_d = m_t - \bar{m}_s$$

The variables m_t, m_d, and f_t are the total number of missing leaflets, the number of missing leaflets due to disease, and the total possible number of leaflets on the main stem, respectively. The latter was estimated by counting the number of nodes on the main stem and multiplying by four leaflets per node. The node of the two cotyledonary branches is designated node "zero" because it is the site of seed leaves. The average number of missing leaflets in the fungicide-treated plots ($\bar{m}_s$) was used as the correction factor. In the fungicide-treated plots, defoliation was assumed to be caused by natural defoliation only, which usually occurs at the lower nodes of the main stem.

Leaflets selected for the estimation of proportion of necrotic area were collected from the selected plant using a variation of the semi-circular template approach (Plaut and Berger, 1980). Twenty leaflets were selected in each of the following semi-circular areas: 1) 0 to 15 cm from the base of the plant, 2) 15 to 30 cm from the base, and 3) above 30 cm from the base. Necrotic leaf area was estimated by counting the number of lesions which were separated in the following classes: 1) lesion diameter of 1 mm and 2) lesion diameter of 4 mm (Shokes *et al*., 1987), and by multiplying the number in each class by the corresponding circular area. The proportion of necrotic leaf area at the canopy level (n_t) was estimated with the following equation:

$$n_t = \frac{\bar{a}_b n_b(1-d_b) + \bar{a}_m n_m(1-d_m) + \bar{a}_u n_u(1-d_u)}{(a_b + a_m + a_u) - (a_b d_b + a_m d_m + a_u d_u)} \qquad [0 \leq (d_b+d_m+d_u) < 3]$$

where n_b, n_m, and n_u are the proportions of necrotic leaf area in the bottom, middle, and top canopy layers, respectively, and d_b, d_m, and d_u, the proportions of defoliation due to disease in the corresponding canopy layers. The coefficients a_b, a_m, and a_u have values of 1, 3, and 5,

respectively, and were determined from the respective semi-circular areas described previously. Finally, the disease severity (s_v) which is a function of both defoliation (d_t) and necrotic leaf area (n_t) is computed with the following equation (Plaut and Berger, 1980):

$$s_v = n_t(1-d_t) + d_t$$

The first part of the equation evaluates the proportion of diseased tissue on non-defoliated leaves, and the second part is the defoliation proportion, itself. The disease severity was transformed with the linearized form of the Richards function (Appendix B):

$$\ln \left| 1 / [(y/y_{max})^{(1-m)}-1] \right| = -\ln (B) + rt \qquad (y \neq 1;\ m \geq 0,\ m \neq 1)$$

$$\text{where } B = y_0^{(1-m)}-1$$

In this Richards function, y is the disease severity, y_{max} the maximum disease severity (y_{max}=1), y_0 the disease severity when time (t) equals zero, and r the rate of disease progress. The parameter m, determining the shape of the curve, was changed within each year to obtain the best coefficient of determination in regressing the transformed disease severity against days after planting. The logistic, Gompertz, and monomolecular functions can be obtained with specific values of Richards m parameter (Appendix B). The monomolecular and the logistic functions are created when m equals 0 and 2, respectively. The Gompertz function is created when m approaches 1.

Prediction of Pod Yield from HAD and HAA

The total pod yield, defined as the sum of the yields of harvested pods and abscised pods, at 135 and 133 DAP in 1986 and 1987, respectively, were used to evaluate the prediction of pod yield as a function of healthy leaf area duration (HAD) and healthy area absorption (HAA) given by Waggoner and Berger (1987):

Predicted Yield = 735 exp{-3.15 exp[-0.00821 (HAD - 93.71)]}

Predicted Yield = -422.7 + (0.472 HAA)

The following equations were used to compute HAD and HAA:

$$HAD = \Sigma \{[(1-x_i)L_i + (1-x_{i-1})L_{i-1}] (t_i-t_{i-1})/2\}$$

$$HAA = \Sigma \{[I_i(1-x_i)(1-\exp(-KL_i)) + I_{i-1}(1-x_{i-1})(1-\exp(-KL_{i-1}))] (t_i-t_{i-1})/2\}$$

where x_i, L_i, t_i, I_i are, respectively, the proportion of diseased leaf area, the leaf area index, the time expressed in DAP, and the insolation that were obtained from sample i. The constant K is the coefficient for absorption of insolation and was estimated at 0.412 (Waggoner and Berger, 1987). The insolation was estimated at 73% of the insolation at the top of the atmosphere at 30° latitude (List, 1966) to obtain the variation from about 23 to 30 MJ m^{-2} d^{-1} that was reported by Waggoner and Berger (1987).

Final Harvest and Peanut Quality

At the end of the growing season, two rows of 6.1 m were harvested in each plot. One row was harvested early at approximately 125 DAP, and the other was harvested late at approximately 140 DAP. Yields of pods, abscised pods, and seeds were obtained. A subsample of 500 g of pods was subjected to a standard peanut quality analysis (Davidson *et al.*, 1982). Additional values obtained from this analysis were the shelling percentage, the number of seeds per pod, the average seed weight, the percentages of extra large kernels (ELK), sound mature kernels (SMK), sound split kernels (SS), and other kernels (OK).

Results and Discussion

Disease Progression

Symptoms of late leafspot were first observed at 51 DAP in 1986 and at 48 DAP in 1987, and were present in all non-treated plots at 70 DAP in 1986 and at 62 DAP in 1987. The experimental fields of 1986 and 1987 were last planted with peanut in 1976 and 1983, respectively. Since the planting date was the same in both years, possible reasons for earlier infection by the pathogen in 1987 are the proximity of the inoculum source and the amount of inoculum. In 1987, peanut was planted in the field adjacent to the peanut field of 1986. The percentage of diseased leaf area never exceeded 10% for the whole canopy in either year (Fig. 2-2). Boote *et al.* (1980) and Pixley (1985), who both used the Horsfall-Barratt scale, reported percentages up to 30% and 20% respectively for the whole peanut canopy. Furthermore, a smooth increase in the percentage of diseased leaf area was not observed as in previous work (Pixley, 1985). This is consistent with the fact that defoliation of peanut leaflets occurred at low percentages of necrotic area and abscised leaflets are not included in the assessment of necrotic area. Therefore, abscission of diseased leaflets reduced the overall percentage of leaf area with lesions in the canopy.

Since leaf abscission was the major component of the effect of late leafspot on peanut, disease severity, which included defoliation, was used as an indicator of disease progression in the field. Transformations of the observed disease severities with the Richards function gave different estimates of the parameter m for 1986 and 1987. The highest coefficient of determination for the regression of transformed values against days after planting, was obtained with m = 0.87 in 1986 (R^2=83%) and m = 2.48

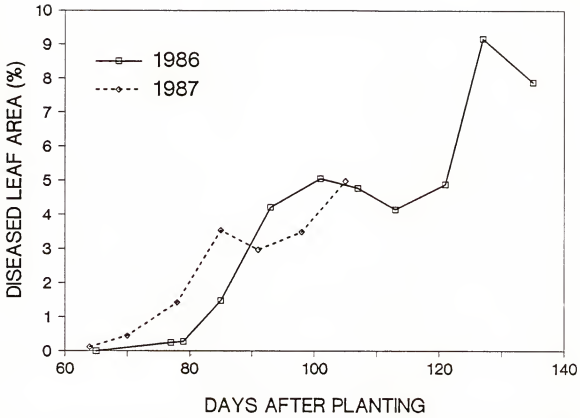


Figure 2-2. Percentage of diseased leaf area as a function of days after planting in non-treated plots.

in 1987 (R^2=98%). Among the usual transformations used in plant epidemiology, the Gompertz function (R^2=82%) gave the highest coefficient of determination, followed by the monomolecular (R^2=74%) and logistic (R^2=57%) functions in 1986. In 1987, the logistic function (R^2=97%) gave the highest coefficient of determination, followed by the Gompertz (R^2=92%) and monomolecular (R^2=78%) functions in 1987. A y_{max} of 1 was assumed for all transformations. Because the m values obtaine with the Richards function were not consistent for 1986 and 1987, the Gompertz function was selected to compare disease progress:

$$-\ln(-\ln(y/y_{max})) = -\ln(B) + rt \qquad (0 < y < 1)$$

where: $B = -\ln(y_0)$

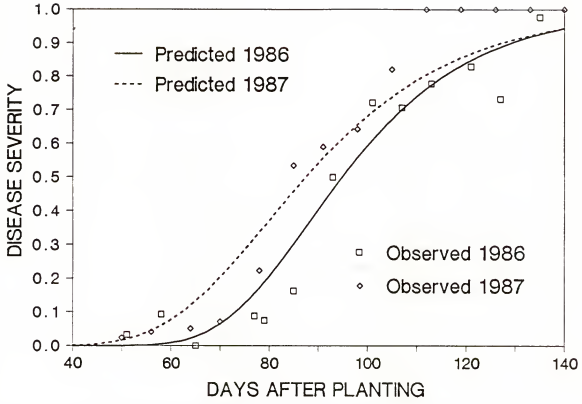


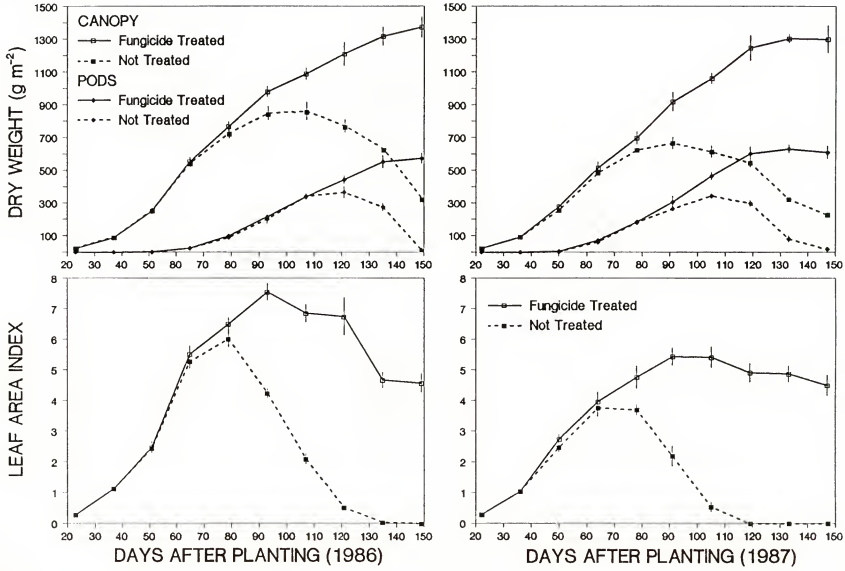
Figure 2-3. Disease severity (visible leafspots and defoliation) as a function of days after planting in the non-treated plots. Predictions were based on the Gompertz function (1986: r=0.055, 1987: r=0.048).

With this function, the disease severity (y) was estimated at 0.01 at 60 DAP in 1986, and at 47 DAP in 1987 (Fig. 2-3). However, the disease progress rate (r) was slightly slower in 1987 (r=0.048) when compared to 1986 (r=0.055).

Effect of Disease on Crop Parameters

The effect of the disease occurred first on the leaves. The leaf dry weight, the leaf area index (LAI), and the dry weight of the total biomass were significantly different at 93 DAP ($P \leq 0.01$) in 1986, and 78 DAP ($P \leq 0.08$) in 1987 between the fungicide-treated and non-treated plots (Fig. 2-4). Light interception, at these dates, was not significantly different ($P \leq 0.05$). It was approximately 2% lower in the non-treated plots. In

Figure 2-4. Effect of late leafspot on the dry weight of the total biomass, dry weight of the pods, and the leaf area index of Florunner peanut in 1986 and 1987. The two treatments were 1) fungicide treated and 2) not treated with fungicides.


DRY WEIGHT (g m-2)
CANOPY
Fungicide Treated
Not Treated
PODS
Fungicide Treated
Not Treated
LEAF AREA INDEX
Fungicide Treated
Not Treated
DAYS AFTER PLANTING (1986)
DAYS AFTER PLANTING (1987)

both years, significant differences in light interception ($P \leq 0.01$) appeared two weeks later when the light interception in the non-treated plots was reduced by approximately 10% and corresponded to a LAI of approximately 2 in the non-treated plots (Tables A-5 and A-6). The high values of light interception with such a low LAI is due to the progressive defoliation of the peanut leaves from the bottom to the top of the canopy (Bell, 1986; Boote *et al.*, 1980). Since the top leaves of the canopy are usually the most efficient under high light intensities, it would be reasonable to assume that a large amount of carbohydrates are produced and translocated to the pods even when a diseased canopy has a LAI at or above 2.0.

No significant differences ($P \leq 0.05$) between the two treatments were observed for the vegetative and reproductive stages, except at the end of the growing season for the reproductive stage. Pods in the non-treated plots reached physiological maturity (R8) earlier than the pods in the fungicide-treated plots. Furthermore, pods in the non-treated plots showed the characteristics of the R9 stage described by Boote (1982) as the overmature stage. He reported that this occurrence was a result of poor late-season control of leafspot, which caused an earlier than normal weakening of pegs and loss of pods for Florunner. Significant differences between fungicide-treated and non-treated plots for the number of pods and seeds, as well as their dry weights, first occurred at 135 DAP ($P \leq 0.01$) in 1986, and at 105 DAP ($P \leq 0.04$) in 1987 (Fig. 2-4). This difference of 30 days between 1986 and 1987 is due to earlier disease progress in 1987 (Fig. 2-3) and a higher LAI in the non-treated plots in 1986 (Fig. 2-4). The peanut canopy was almost completely defoliated ($LAI \leq 0.5$) at 121 DAP in 1986, and at 105 DAP in 1987 (Fig. 2-4).

Peg Deterioration and Pod Losses

The necrotic area and the defoliation induced by late leafspot reduced the potential yield of Florunner peanut by 37 and 46% in 1986 and 1987, respectively (Table 2-1). The potential yield was defined as the highest pod yield observed in each treatment. However, most of this potential yield can not be recovered with standard harvesting equipment because many pods are not recovered. They remain in the soil when the peanut plants are harvested. These losses at harvest, which are commonly referred to as dropped pods, may be caused by the deterioration of the pegs. Some of this peg deterioration occurs naturally in fungicide-treated plots at the end of the growing season and seems to be related to natural aging and is accelerated by high soil moisture and high soil temperature in the pegging zone (Boote, unpublished). Troeger *et al.* (1976) observed a significant reduction in the peg attachment force with an increase in shelling percentage, which is an index of pod maturity. In non-treated plots, the peg deterioration was greatly enhanced soon after the peanut canopy was completely defoliated. Complete defoliation removes the source of photosynthates necessary to maintain the pegs, which are then more susceptible to infection by saprophytic microorganisms. Furthermore, defoliated leaves on the soil provide a good medium for microbial growth, which may contribute to peg deterioration, especially with high soil moisture and high soil temperature in the pegging zone.

To characterize the abscission of pods, expressed as the fraction of abscised pod dry weight over the total pod dry weight (Table 2-1), the Richards function was used to find the m value that best described the time course of disease effects on pod abscission for 1986 and 1987 in the non-treated plots. Again, different estimates of the parameter m were

Table 2-1. Yield of harvested and dropped pods for fungicide-treated and non-treated peanut treatments during summers of 1986 and 1987 in Gainesville, Florida.†

Days after Planting	Fungicide Treated			Not Treated		
	Harvested Pods	Dropped Pods	Total Pods	Harvested Pods	Dropped Pods	Total Pods
	g m^{-2}					
			1986			
93	216.2	0.0	216.2	201.5	0.0	201.5
107	338.1	0.0	338.1	341.2	0.0	341.2
121	444.0	1.0	445.0	366.1	5.6	371.7
135	552.7	15.9	568.6	276.6	111.0	387.6
149	573.9	45.1	619.0	13.6	240.2	253.8
			1987			
91	307.6	0.0	307.6	337.8	0.0	337.8
105	466.8	0.0	466.8	344.0	0.0	344.0
119	603.5	0.0	603.5	298.8	37.2	336.0
133	633.0	7.6	640.6	80.9	241.5	322.4
147	610.4	27.6	638.0	18.8	290.0	308.8

† Yield of pods was obtained from samples taken in a one meter section of the row (4 replications).

obtained for 1986 and 1987. The highest coefficient of determination for the regression of transformed values of pod abscission against days after planting was obtained with m = 2.72 in 1986 (R^2=96%) and m = 0 in 1987 (R^2=91%). Again the three usual transformations of plant epidemiology were used. For 1986, the logistic function (R^2=95%) gave the highest coefficient of determination, followed by the Gompertz (R^2=86%) and monomolecular (R^2=69%) functions. In 1987, the monomolecular function (R^2=91%) gave the highest coefficient of determination, followed by the Gompertz (R^2=86%) and logistic (R^2=83%) functions. A y_{max} of 1 was assumed for all transformations. Because the m values obtained with the Richards function were not consistent for 1986 and 1987, the Gompertz function was

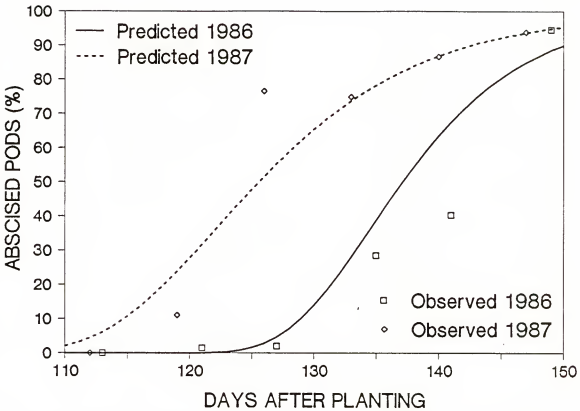


Figure 2-5. Deterioration of the pegs causing pod losses of Florunner peanut in non-treated plots during the growing seasons of 1986 and 1987 in Gainesville, Florida. Predictions were based on the Gompertz function (1986: r=0.146, 1987: r=0.116).

selected to compare the abscission of pods (Fig. 2-5). The abscission of pods progressed faster in 1986 (r=0.146) than in 1987 (r=0.116), and the percentage of abscised pods reached 1% at 124 DAP in 1986 and 107 DAP in 1987, when estimated with the Gompertz function. Similar trends in timing and rates were obtained with disease severity in the two years. Whether or not pod abscission was induced by late leafspot or was a consequence of the effects of late leafspot was not determined.

Prediction of Pod Yield from HAD and HAA

The predictions of total pod yield (Y_T) and harvested pod yield (Y_H) with HAD and HAA were adequate in 1986 and 1987 for the fungicide-treated

plots, except for the prediction with HAD in 1986. The peanut crop of 1986 had a LAI that was very high compare to other years (Table 2-2). The effect of this excessive foliage was reduced by using HAA which accounts for light interception. Under fungicide-treated conditions, pod losses are minimal, and the Y_T is almost equivalent to Y_H. When no fungicides are applied, the peanut canopy defoliates completely, and pod losses are very important. The prediction of Y_H, which was used by Waggoner and Berger (1987), with HAD and HAA was overestimated in 1986 and 1987. The prediction of Y_T with HAD and HAA was adequate in 1986, but was underestimated in 1987 (Table 2-2). The concept of HAD and HAA is difficult to apply when pod losses occur after complete defoliation of the peanut canopy. HAD and HAA represent the photosynthetic potential of a canopy, and they both become constant after complete defoliation, while Y_H of peanut continues to decrease. Y_T remains relatively constant after complete defoliation of the canopy, and is a better indicator of the cumulative photosynthetic potential of a peanut canopy that is defoliated by late leafspot.

Since different results were obtained for the prediction of Y_T in 1986 and 1987, two other sets of data were used to evaluate the predictive value of HAD and HAD: 1983 (Pixley, 1985) and 1985 (Pixley, unpublished). In both 1983 and 1985, the prediction of Y_T and Y_H with HAD and HAA was adequate for fungicide-treated plots. The prediction of Y_H was overestimated in both years, and the prediction of Y_T was underestimated in both years (Table 2-2). However, the prediction of Y_T was close in 1985, but prior to 140 DAP, total pod yields of about 300 g m^{-2} were observed in these peanut fields. Such yields would cause a greater underestimation of Y_T in 1985. According to the results obtained in three

Table 2-2. Prediction of the pod yield with the healthy leaf area duration (HAD) and the healthy area absorption (HAA) (Waggoner and Berger, 1987) for peanut grown in 1983 (Pixley, 1985), 1985 (Pixley, unpublished), 1986, and 1987.

	Fungicide Treated				Not Treated			
	1983	1985	1986	1987	1983	1985	1986	1987
				Field Observations†				
DAP	131	140	135	133	131	140	135	133
Maximum LAI	4.78	4.62	7.55	5.44	4.33	3.93	6.02	3.76
Total Yld (Y_T)	531.1	532.2	568.7	640.7	427.3	201.3	387.7	322.6
Harv. Yld (Y_H)	471.1	498.1	552.8	633.0	214.0	7.0	272.6	81.0
				Yield Prediction from HAD‡				
HAD	367.1	382.6	551.7	428.6	237.0	183.4	304.3	190.8
Pred. Yield	526.3	547.8	683.0	600.8	278.2	162.6	420.2	177.8
Dev. from Y_T	-4.8	+15.6	+114.3	-39.9	-149.1	-38.7	+32.5	-144.8
Dev. from Y_H	+55.2	+49.7	+130.2	-32.2	+64.2	+155.6	+147.6	+96.8
				Yield Prediction from HAA§				
HAA	2064.	1907.	2190.	2065.	1545.	1167.	1648.	1285.
Pred. Yield	551.3	477.5	611.2	552.0	306.7	128.1	355.4	184.0
Dev. from Y_T	+20.2	-54.7	+42.5	-88.7	-120.6	-73.2	-32.3	-138.6
Dev. from Y_H	+80.2	-20.6	+58.4	-81.0	+92.7	+121.1	+82.8	+103.0

† Yields reported are pod yields in g m^{-2}. The total pod yield (Y_T) is the sum of the abscised pod yield and the harvested pod yield (Y_H). The maximum leaf area index (LAI) was assumed to be the highest LAI used in the calculations of HAA and HAD.

‡ Pred. Yield = 735 exp{-3.15 exp[-0.00821 (HAD - 93.71)]}, (Waggoner and Berger, 1987); Deviations from Y_T and Y_H were calculated by subtracting Y_T and Y_H, respectively, from the yield predicted with HAD.

§ Pred. Yield = -422.7 + (0.472 HAA), (Waggoner and Berger, 1987); Deviations from Y_T and Y_H were calculated by subtracting Y_T and Y_H, respectively, from the yield predicted with HAA.

out of four years, the concepts of HAD and HAA were not adequate to predict total pod yield of a peanut crop defoliated by late leafspot and with necrotic lesions on the attached leaves.

Final Harvest and Peanut Quality

Finally, in the final harvests, pod and seed yields in the non-treated plots were significantly reduced ($P \leq 0.05$) for early (122-126 DAP)

and late (136-140 DAP) harvests in both years (Table A-7). Pod and seed numbers were also significantly reduced ($P \leq 0.01$) in all cases. In the non-treated plots, the shelling percentage was significantly higher ($P \leq 0.05$), the number of seeds per pod significantly higher ($P \leq 0.05$), and the average weight of a seed significantly lower ($P \leq 0.05$). Bell (1986) observed a significant reduction in kernel size at final harvest and no significant differences in shelling percentage. The percentages of extra large kernels (ELK) and sound mature kernels (SMK) were not significantly different for both harvests in 1986, but non-treated plots had a slightly lower ELK percentage and a slightly higher SMK percentage. This same trend was observed in 1987, but the differences were significant ($P \leq 0.05$).

Conclusion

Late leafspot appears to have a significant effect on every part of the peanut plant. The fungus first attacks the leaves which subsequently defoliate at a very rapid rate. The loss of green photosynthetic leaf area causes significant reductions in partitioning of carbohydrates to the stems and to the pods. Potential reproductive yield was reduced by 50% in 1986 and 1987. However, peg deterioration is also enhanced after complete defoliation. Further reproductive yield is lost if the crop is not harvested soon after complete defoliation. Under high soil moisture and high temperature in the pegging zone, the peg deterioration progresses very rapidly.

To describe disease severity and peg deterioration for both 1986 and 1987, the Gompertz function was selected as an intermediate alternative function to fit the data for both years. The Richards function provided the best statistical fit to the disease severity data within each year, but the m values were very different between the years. The utilization

of such functions to describe disease progress is more appropriate within a year where the inoculum source and environmental conditions are the same. The effect of environmental factors, such as relative humidity and air temperature, on the progress of late leafspot disease needs to be investigated to forecast or predict initiation of disease and its rate of progress. Furthermore, the host plant plays an important role in disease progress. The presence of leaves is essential for the development of late leafspot. The epidemic and resulting yield loss are a complex interaction between the disease, the crop, and the environment. With the use of simple disease-progress functions, the progression of a given disease can be described within a year, but this description may not be adequate to provide understanding of the complexity of a given pathosystem, and to predict disease progression in different years.

CHAPTER 3

EFFECT OF LATE LEAFSPOT ON FLORUNNER PEANUT LEAFLET AND CANOPY PHOTOSYNTHESIS

The photosynthetic unit of the peanut plant is the tetrafoliate, pinnately compound leaf with two opposite pairs of leaflets. Leaves of non-stressed peanut plants tend to be oriented at right angles with the direction of the incident radiation and follow the sun in this position. The peanut leaf folds its four leaflets upon each other at night (Ketring *et al.*, 1982) and in response to water stress (Allen *et al.*, 1976). The leaf anatomy is typical to dicotyledonous plants with a palisade parenchyma that is well developed. The lower epidermis is characterized by a layer of non-chlorophyllous cells that accounts for approximately 25% of the leaf thickness (Ketring *et al.*, 1982). The specific leaf area, defined as the leaf area per unit of leaf dry weight, ranges from 150 to 245 $cm^2\ g^{-1}$ in young leaves that are fully expanded (Bhagsari and Brown, 1976a; Pallas and Samish, 1974). Photosynthetic response to different levels of light intensity is strongly influenced by the light intensity under which the plants were grown or pre-treated. Young leaves have higher net photosynthesis rates than older leaves. When exposed to higher light intensities, lower leaves in the canopy have lower photosynthetic potential than higher leaves in the canopy (Henning *et al.*, 1979; Trachtenberg and McCloud, 1976). Maximum apparent photosynthesis rates for peanut leaves range from 0.6 to 1.8 mg $CO_2\ m^{-2}\ s^{-1}$ (Bhagsari and Brown,

1976a; 1976b; Bhagsari *et al.*, 1976; Gallaher *et al.*, 1976; Henning *et al.*, 1979; Pallas, 1980; Pallas and Samish, 1974; Trachtenberg and McCloud, 1976) with a mean value of 1.06 mg CO_2 m^{-2} s^{-1} (Ketring *et al.*, 1982). Pallas and Samish (1974) evaluated photosynthesis at light intensities from 180 to 1546 μE m^{-2} s^{-1}. Leaf photosynthesis was not light-saturated in that range. Trachtenberg and McCloud (1976) obtained a theoretical maximum photosynthesis of 2.1 mg CO_2 m^{-2} s^{-1} which was obtained by extrapolation of a Lineweaver-Burke plot. They also obtained a light compensation point of 27 μE m^{-2} s^{-1} for peanut leaves.

The presence of necrotic lesions on plant leaves is well known to reduce light interception and consequently leaf photosynthesis. Early leafspot, induced by *Cercospora arachidicola* Hori, and late leafspot, induced by *Cercosporidium personatum* (Berk. & Curt.) Deighton, are two pathogens causing necrotic lesions on peanut leaves. Another effect of both pathogens is the induction of leaflet abscission which causes important reductions in the leaf area index (LAI) of the canopy. Early defoliation has been associated to an increase in ethylene levels in the infected leaflets of peanut (Ketring and Melouk, 1982), and to the presence of a toxin produced by these pathogens, cercosporin (Abo-El-Dahab *et al.*, 1985; Venkataramani, 1967). Ethylene is a growth regulator that can induce premature abscission of leaves and other organs (Ketring and Melouk, 1982), and cercosporin is a photosynthesizing toxin activated by light (Daub, 1982; Daub and Hangarter, 1983).

Boote *et al.* (1983) proposed a classification of diseases based on their effect on the physiology of the crop. For Cercospora leafspots, they hypothesized that "disease effects on photosynthesis were mediated through: loss of LAI (senescence acceleration), self-shading of healthy

leaf area by leaf spots (light stealing), and a toxic effect of leaf spot disease on the photosynthetic mechanism of the remaining leaves". Whether or not this toxic effect includes the physical invasion of host cells by the pathogen itself, was not discussed. The relative importance of each factor in the reduction of canopy photosynthesis is not fully understood. Severe damage from Cercospora leafspot reduced LAI by 80% and canopy carbon exchange rate (CER) by 93% at 119 days after planting in 1977 (Boote *et al.*, 1980). Total leafspot severities (necrosis plus disease-induced defoliation) of approximately 11 and 56% induced reductions in canopy apparent CER of 35 and 65%, respectively at 91 days after planting in 1978 (Boote *et al.*, 1980). Subrahmanyam *et al.* (1984) found that peanut yields were highly correlated with the percentage of remaining green leaf at maturity and they proposed that the effect of partly infected leaves on photosynthesis efficiency was small within the context of the whole crop. The effect of Cercospora leafspot was also evaluated on individual leaflets by Boote *et al.* (1980). The photosynthetic capacity of peanut leaflets was quickly reduced by the presence of Cercospora leafspot, and was expressed with the following relation:

$$y = 100 \exp(-0.3308\ x^{0.5}),\ R^2 = 0.99$$

where y is the carbon uptake of diseased leaves expressed as a percent of disease-free leaves, and x is the percentage of leafspot damage on intact leaves. This relation was developed for a population of peanut leaflets with different levels of necrotic lesions, and having variable but unknown leaf ages. This last factor was proposed to confound the results obtained because the youngest leaves have less leafspot damage and higher rates of photosynthesis than the oldest leaves (Boote *et al.*, 1980).

The objectives of this research were 1) to assess quantitatively the reduction in photosynthesis of peanut leaflets at the same age when necrotic lesions can be observed on the leaflets, and 2) to determine if the reduction in LAI, induced by the presence of the pathogen, is the major factor causing reduction in canopy photosynthesis measured in the field. From the last objective, we hypothesized that the reduction in canopy photosynthesis due to diseased leaf area is negligible compared to reduction in canopy photosynthesis caused by extensive disease-induced defoliation.

Materials and Methods

The experiment was conducted at the Agronomy Farm of the University of Florida in Gainesville. Florunner peanut (*Arachis hypogaea* L.) was planted on 2 June during summers of 1986 and 1987 at a rate of 20 plants m^{-1} in rows 0.91 m apart to achieve a population of 13 to 14 plants m^{-2}. Irrigation with overhead sprinklers provided water to the field when needed. Weeds were controlled with pre-plant and pre-emergence herbicides. Escaped weeds were removed manually after plant emergence. Insecticides were applied as needed to insects. Gypsum was applied at a rate of 1009 and 1345 kg ha^{-1} in 1986 and 1987, respectively, at the pegging stage which occurred 40 to 42 days after planting (Table A-1).

The experimental design was a completely randomized block with two treatments: 1) fungicide treated and 2) not treated, and four replications. The fungicide chlorothalonil was used at a rate of 2.3 l ha^{-1}. Applications of fungicide began 32 and 23 days after planting in 1986 and 1987, respectively. Time between applications was between 8 and 12 days, and sprays were applied until the first week of October.

Carbon Exchange Rate of Peanut Leaflets

In each field plot, 10 fully expanded leaflets at the tip of the main stem were tagged with colored wires at 90 days after planting in 1986, and at 63, 77, and 93 days after planting in 1987. On a given day, one tagged leaf in each plot was measured for CER under full sunlight with the portable photosynthesis system of LI-COR (1986: LI-6000; 1987: LI-6200). A chamber of 0.25 l in volume from LI-COR was used to measure leaflet CER. Table 3-1 gives the dates when leaflet CER was measured. The percentage of necrotic leaf area on each leaflet was estimated by the technique described in the section on disease assessment.

Carbon Exchange Rate of the Peanut Canopy

Starting eight weeks after planting, 0.61 m of row in two blocks, which consisted of two treatments each, were selected on a bi-weekly basis for measurements of canopy CER. Canopy CER was measured on seven dates in 1986 and on eight dates in 1987. Percent light interception was determined using a line quantum sensor (LI-COR LI-191SA). A chamber made of aluminum frame covered with mylar film (Boote *et al.*, 1980; Jones *et al.*, 1982) was used to estimate canopy CER. The total chamber was 0.50 m^3 in volume and 0.56 m^2 in cross-sectional area (0.61 m X 0.91 m). The chamber consisted of two distinct parts: a permanent chamber base that was pushed into the soil approximately 4 cm, and a portable chamber cover that was clamped onto the base during the measurement of CER. A gasket of weatherstripping provided an air-tight seal between the base and the cover when secured by vise-grip clamps. The chamber cover contained two electric fans that provided uniform mixing of the air when the chamber was closed. The portable photosynthesis system of LI-COR was used to measure canopy CER. The 0.25 l chamber from LI-COR was opened and placed

Table 3-1. Dates when peanut leaves were tagged and dates when carbon exchange rate (CER) of peanut leaflets was measured during summers of 1986 and 1987 at the University of Florida in Gainesville.

Experiment of 1986	Experiment of 1987		
	Tagging no.1	Tagging no.2	Tagging no.3
	Leaf Tagging Date		
31 August	4 August	18 August	3 September
	Date of Measurement of Leaflet CER		
6 September	18 August	26 August	15 September
13 September	21 August	29 August	
20 September	26 August	5 September	
27 September	29 August	15 September	
	5 September		
	15 September		

inside the large chamber prior to clamping on the portable chamber cover. Canopy CER was measured for four different light intensities: 1) full sunlight, 2) 50% sunlight which was achieved by covering the large chamber with one white cotton sheet, 3) 25% sunlight which was achieved by covering the large chamber with two white cotton sheets, and 4) 0% sunlight-darkness which was achieved by covering the large chamber with a black plastic tarp. The upper part of the large chamber was removed between each measurement, except between 25% sunlight and dark, to allow the return of CO_2 to ambient levels (340 to 350 ppm). Leaflet CER was measured on two leaflets in each of the four plots (two fungicide-treated and two non-treated plots) where canopy CER was measured. A leaflet on the third node from the tip of the main stem was selected. After all these measurements the base of the chamber was removed and the whole 0.61 m of row was sampled and subjected to standard measurements and analysis of growth (Chapter 2).

Disease Assessment

Late leafspot disease was assessed on each plant selected for the standard growth analyses. The selected plant was an average representative plant from the whole sample harvested in the canopy chamber. Defoliation was assessed by counting the number of missing leaflets on the main stem. This estimation was further corrected for defoliation due to natural senescence at the lower nodes of the main stem. The defoliation due to disease (d_t) was estimated with the following equation:

$$d_t = m_d / (f_t - \bar{m}_s) \qquad (m_d \geq 0)$$

$$\text{where } m_d = m_t - \bar{m}_s$$

The variables m_t, m_d, and f_t are the total number of missing leaflets, the number of missing leaflets due to disease, and the total possible number of leaflets on the main stem, respectively. The latter was estimated by counting the number of nodes on the main stem and multiplying by four leaflets per node. The node of the two cotyledonary branches is designated node "zero" because it is the site of seed leaves. The average number of missing leaflets in the fungicide-treated plots ($\bar{m}_s$) was used as the correction factor. In the fungicide-treated plots, defoliation was assumed to be caused by natural defoliation only, which usually occurs at the lower nodes of the main stem.

Leaflets selected for the estimation of the proportion of necrotic area were collected from the selected plant using a variation of the semi-circular template approach (Plaut and Berger, 1980). Twenty leaflets were selected in each of the following semi-circular areas: 1) 0 to 15 cm from the base of the plant, 2) 15 to 30 cm from the base, and 3) above 30 cm from the base. Necrotic leaf area was estimated by counting the number

of lesions which were separated in the following classes: 1) lesion diameter of 1 mm, and 2) lesion diameter of 4 mm (Shokes *et al.*, 1987), and by multiplying the number in each class by the corresponding circular area. The proportion of necrotic leaf area at the canopy level (n_t) was estimated with the following equation:

$$n_t = \frac{a_b n_b(1-d_b) + a_m n_m(1-d_m) + a_u n_u(1-d_u)}{(a_b + a_m + a_u) - (a_b d_b + a_m d_m + a_u d_u)} \qquad [0 \leq (d_b+d_m+d_u) < 3]$$

where n_b, n_m, and n_u are the proportions of necrotic leaf area in the bottom, middle, and top canopy layers, respectively, and d_b, d_m, and d_u, the proportions of defoliation due to disease in the corresponding canopy layers. Finally, the disease severity (s_v) which is a function of both defoliation (d_t) and necrotic leaf area (n_t) is computed with the following equation:

$$s_v = n_t(1-d_t) + d_t$$

The first part of the equation evaluates the proportion of diseased tissue on non-defoliated leaves, and the second part is the defoliation proportion, itself.

Results and Discussion

Leaflet Photosynthesis

The CER of peanut leaflets was significantly affected by the degree of damage on the leaflet, which was expressed as the percentage of necrotic leaf area. The relation between leaflet CER and the degree of damage on the leaflet was linear when CER was expressed as a percentage of the CER of leaflets in fungicide-treated plots (Fig. 3-1, Table C-1). The tagging of leaflets resulted in the removal of the confounding of leaf age that was suggested by Boote *et al.* (1980). The function obtained by

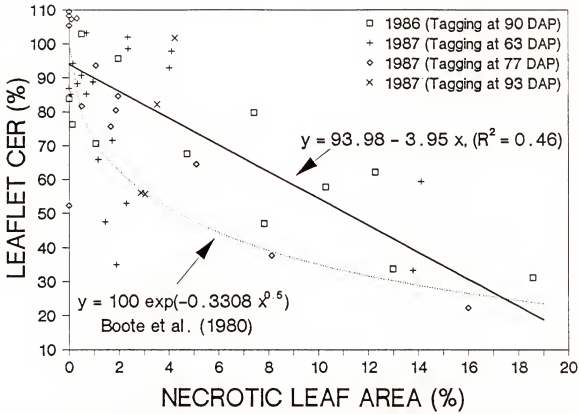


Figure 3-1. Effect of the percentage of necrotic leaf area on leaflet CER, which was expressed as the percentage of leaflet CER in fungicide-treated plots.

Boote *et al.* (1980) was not adequate to represent the effect of damage by late leafspot on the CER of peanut leaflets (Fig. 3-1). However, the coefficient of determination obtained with the linear function was rather low (R^2 = 46%), meaning that only 46% of the total variation could be explained by the linear regression. The rest of the variation was probably due to differences between blocks in the experimental design, differences in water status between leaflets, and differences in light intensity from one measurement to the other.

The linear regression suggests that 15% necrotic leaf area lead to a reduction of 65% in the CER of infected leaflets. Thus, it appears that there was an effect on leaflet photosynthesis due to host cells invaded by the pathogen, which is the infected leaf area ahead of the necrotic

leaf area. Whether or not a toxin, like cercosporin, is involved in further reductions of leaflet photosynthesis, is not known. The necrotic leaf area does not represent the leaf area that is infected by the pathogen. It takes approximately 10 to 12 days from the infection by the pathogen to the appearance of the first necrotic lesions of late leafspot. The pathogen continues to expand inside the leaf, and infected leaf area may explain the large reduction in the CER of peanut leaflets with low percentages of necrotic leaf area.

Canopy Photosynthesis

The CER of the peanut canopy measured in this experiment under full sunlight is equivalent to the apparent canopy photosynthesis (ACP) rate. ACP results from three components of CO_2 flux: 1) the uptake of CO_2 by photosynthesizing tissue, 2) the efflux of CO_2 from the respiration of above-ground tissue, and 3) the efflux of CO_2 from the soil-root-microbial system (Boote *et al.*, 1985a). The last two components were measured when plants and soil were placed temporarily in darkness. With these measurements, it is possible to estimate the total canopy photosynthesis (TCP), defined as the total uptake of CO_2 by photosynthesizing tissue (Boote *et al.*, 1985a). Significant treatment differences in ACP first occurred at 101 days after planting in 1986 (Fig. 3-2, Table C-2), and at 98 days after planting in 1987 (Fig. 3-3, Table C-3). At these times in 1986 and 1987, the light interception was 90 and 70% which was associated with LAI of 2.33 and 1.73, respectively. The high light interception achieved with such low LAI is caused by two factors: 1) the disease-induced defoliation progresses from the bottom to the top of the peanut canopy, but the canopy maintains uniform horizontal leaf coverage, and 2) stems remain to intercept light. Upper leaves in a peanut canopy have

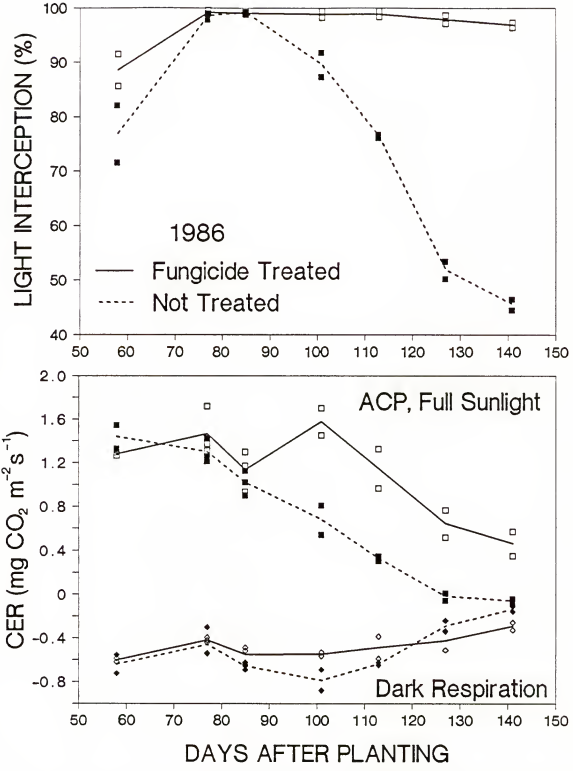


Figure 3-2. Light interception, apparent canopy photosynthesis (ACP), and dark respiration of fungicide-treated and non-treated peanut canopies during summer 1986. The carbon exchange rate (CER) is expressed in mg CO_2 m^{-2} s^{-1}.

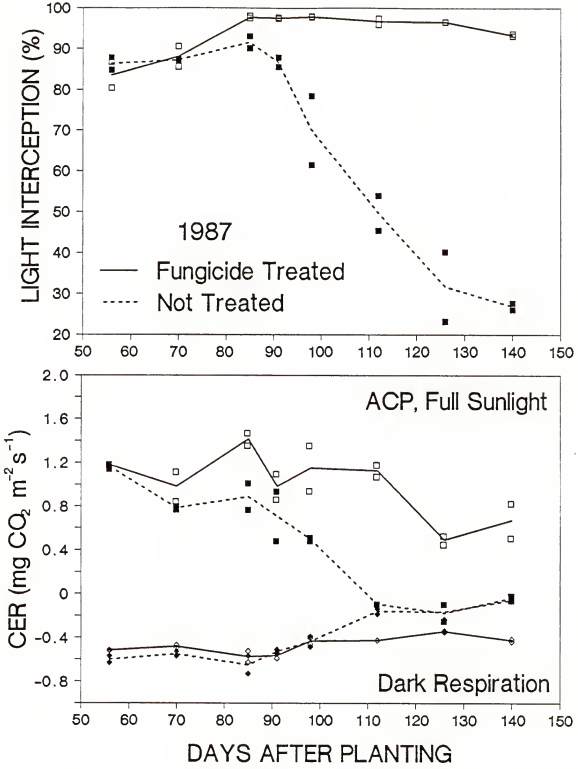


Figure 3-3. Light interception, apparent canopy photosynthesis (ACP), and dark respiration of fungicide-treated and non-treated peanut canopies during summer 1987. The carbon exchange rate (CER) is expressed in mg CO_2 m^{-2} s^{-1}.

greater photosynthetic rates than the lower leaves. No significant trends were observed for dark respiration during both years, except that the absolute value of dark respiration was significantly reduced after complete defoliation of the peanut canopy at 127 and 112 days after planting in 1986 and 1987, respectively (Fig. 3-2 and 3-3).

Reductions in ACP due to leafspot were observed during both years. To evaluate if reduction in TCP was mainly due to a reduction in LAI, the following equations were used (Boote and Jones, 1987):

$$F_c = F_{sl} + F_{sh}$$

$$F_{sl} = \frac{F_{lx}}{k}\left[1 - \exp\left(\frac{-\epsilon k I}{F_{lx}}\right)\right][1 - \exp(-kL)]$$

$$F_{sh} = L_{sh} F_{lx}\left\{1 - \exp\left[\frac{-\epsilon m I\,(1 - \exp(-kL_{sh}))}{L_{sh}\,F_{lx}}\right]\right\}$$

$$L_{sh} = L - L_{sl}$$

$$L_{sl} = (1/k)\,[1 - \exp(-kL)]$$

These equations compute the response of gross canopy assimilation (F_c) to LAI (L) and photosynthetic photon flux density (I). The variable L is divided into the sunlit LAI (L_{sl}) and the shaded LAI (L_{sh}), which give gross canopy assimilation of sunlit leaves (F_{sl}) and shaded leaves (F_{sh}), respectively. Information on canopy light extinction (k), leaf quantum efficiency (ϵ), leaf transmission coefficient (m), and the maximum photosynthetic rate of a single leaf (F_{lx}) are assumed to be available (Boote and Jones, 1987). Data from the experiment provided information on F_c, I, and L for each measurement of canopy photosynthesis in the field. Values of k and m were obtained from observations in the field, and ϵ was obtained from the literature (ϵ=0.0023 mg CO_2 μE^{-1}) (Ehleringer and Björkman, 1977; Boote and Jones, 1987). The ultimate objective in the use of these equations is to solve for F_{lx} in each set of measurements of

Table 3-2. Effect of late leafspot on measured leaf area index (L), disease severity (s_v), and computed maximum leaf photosynthesis (F_{lx}) which was estimated with the equations of Boote and Jones (1987).

Mth	Day	DAP	Fungicide Treated L	Fungicide Treated s_v	Fungicide Treated F_{lx}	Not Treated L	Not Treated s_v	Not Treated F_{lx}	F for F_{lx}
			m^2m^{-2}	%	mg $m^{-2}s^{-1}$	m^2m^{-2}	%	mg $m^{-2}s^{-1}$	
			1986 (k=0.74, m=0.06, ϵ=0.0023†)						
7	30	58	3.15	0.77	1.72	4.03	9.31	1.92	0.28 ns
8	18	77	5.63	5.43	1.41	6.17	8.84	1.17	3.82 ns
8	26	85	7.33	0.70	1.11	5.94	16.35	1.16	0.17 ns
9	11	101	7.75	2.00	1.64	2.33	72.15	1.36	1.33 ns
9	23	113	8.05	1.12	1.07	1.74	77.80	0.94	7.20 ns.
10	7	127	4.53	14.76	0.62	0.40	73.32	0.88	2.28 ns
10	21	141	4.85	9.25	0.42	0.03	100.00	0.39	1.00 ns
			1987 (k=0.68, m=0.06, ϵ=0.0023†)						
7	28	56	2.72	0.41	1.30	3.31	4.12	1.35	0.45 ns
8	11	70	3.68	0.46	0.96	3.66	7.06	0.84	1.31 ns
8	26	85	4.74	0.77	1.40	2.31	53.39	1.38	0.01 ns
9	1	91	4.52	1.20	0.95	1.69	55.30	1.37	0.97 ns
9	8	98	4.96	0.74	0.93	1.73	64.34	0.92	0.01 ns
9	22	112	4.58	0.96	0.96	0.00	100.00	-‡	-§
10	6	126	4.24	0.32	0.41	0.00	100.00	-	-
10	20	140	5.01	1.17	0.59	0.00	100.00	-	-

ns Not significant at the 0.10 probability level.
† ϵ is expressed in mg CO_2 μE^{-1}
‡ F_{lx} was not computed because the canopy was completely defoliated in the non-treated plots.
§ F was not computed because there was only one treatment to compare.

canopy photosynthesis, and to compare the resulting values of F_{lx} between fungicide-treated and non-treated plots. A data set consists of canopy CER measured at the four light intensities, and within a given treatment and date. The procedure of non-linear regression (NLIN) from SAS (1985) was used to solve for F_{lx} while the other known parameters were inputs in the program. Only the LAI was different between the sets of measurements. Results from this test are given in Table 3-2. No significant differences

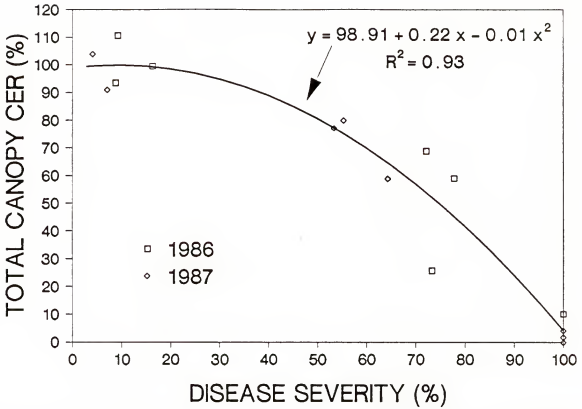


Figure 3-4. Effect of the disease severity on the total canopy photosynthesis (TCP) expressed as a percentage of TCP measured in fungicide-treated plots on the same date.

were found between the F_{lx} of the fungicide-treated and the non-treated plots, which suggests that the reduction in LAI was the major component involved in the reduction of canopy photosynthesis due to the effect of late leafspot. Computed F_{lx} were in the range of reported F_{lx} in the literature, which is from 0.6 to 1.8 mg CO_2 m^{-2} s^{-1} (Ketring *et al.*, 1982), but they were in most cases higher than the leaflet CER measured under full sunlight in the field experiments (Table C-4).

Like with leaflet photosynthesis, the total canopy photosynthesis (TCP) of non-treated plots was expressed as a percentage of TCP observed in fungicide-treated plots, and was related to the disease severity observed in non-treated plots (Fig 3-4). As mentioned previously, the disease severity is an expression of both defoliation and necrotic area

on the attached leaves. Based on the quadratic function obtained, there was a reduction of 50% in TCP when the disease severity was 80%. As shown in Chapter 2, the defoliation is the major component of disease severity of late leafspot. Then, according to these results, the reduction in LAI due to defoliation by late leafspot was the major factor that reduced canopy photosynthesis. In fact, the curve is substantially a reversed picture of TCP response to LAI, where 100% disease severity is zero LAI.

Conclusion

The effect of late leafspot on leaflet photosynthesis was not explained completely by the percentage of necrotic area on the leaflets. Rather, the effect appears to be four times greater than the necrotic area, and probably reflects the infected area, defined as the area where host cells are invaded by the pathogen, and which extends beyond the visible necrotic area. The potential effect of a toxin, like cercosporin, on the leaflet photosynthesis may be limited to the host cells invaded by the pathogen. A systemic action, which would affect the photosynthetic rate of host cells that are not infected, was not reported for cercosporin. If it were possible to quantify the infected leaf area, the effect of cercosporin on leaflet photosynthesis could probably be evaluated.

Reductions in canopy photosynthesis due to the effect of late leafspot were explained adequately by a reduction in the leaf area index (LAI). The reduction in light interception due to necrotic lesions on attached leaves, and the reduction in the photosynthetic efficiency of attached leaves due to the presence of a toxin were negligible factors according to the results obtained in this experiment.

CHAPTER 4

SIMULATION MODEL OF LATE LEAFSPOT AFFECTING PEANUT: I. DESCRIPTION OF THE MODEL

Early leafspot, induced by *Cercospora arachidicola* Hori, and late leafspot, induced by *Cercosporidium personatum* (Berk. & Curt.) Deighton, are important foliar diseases affecting peanut (*Arachis hypogaea* L.) in the southeastern United States. In some regions, late leafspot is the predominant disease, and in others, early leafspot is. For instance, in Florida, late leafspot is the disease observed more commonly in the peanut fields. Both diseases cause necrotic lesions on leaflets, reduce their photosynthetic rate, and induce early senescence. Reductions in yield can be very important if the diseases are not controlled with fungicides such as chlorothalonil.

There is major interest in the forecasting of early and late leafspot to reduce applications of costly fungicides. Jenson and Boyle (1965; 1966) developed a technique to forecast the development of early leafspot based on the number of consecutive hours of relative humidity over 95%, and the minimum temperature during this period of high relative humidity. This technique was computerized by Parvin *et al.* (1974) and tested by Phipps and Powell (1984). The Jenson and Boyle model was developed in relation to the general disease progression in the field. Knudsen *et al.* (1987) used it for the infection process in a simulation model of Cercospora leafspot, but Shew *et al.* (1988) found that the Jenson and

Boyle approach was not appropriate to predict infection by late leafspot. Early and late leafspot are caused by two different pathogens and their response to environmental conditions is different. Information on the effect of the environment on dissemination, germination, sporulation, and spore release of early leafspot has been published (Alderman and Beute, 1986; 1987; Alderman *et al.*, 1987). Nutter (1988) is presently determining the effect of the environment on spore release of late leafspot.

The objective of this research is to develop a simulation model of the progression of late leafspot disease with information available in the literature, and to couple it to PNUTGRO, a simulation model of the development and growth of peanut. The simulation model of the progression of late leafspot disease was named LATESPOT. The ultimate goal is to predict reductions in production of dry matter by the disease with a leafspot model that contains as much biological realism as possible. In a joint article, the late leafspot model is calibrated against field observations collected during 1986 in Gainesville, Florida, and validated against independent field data sets collected in 1983, 1985, and 1987. The four years represented a range of planting dates and locations in Florida.

Peanut Growth and Development

PNUTGRO V1.02 was developed during 1985-1989 at the University of Florida by an interdisciplinary research team. PNUTGRO is a process-oriented simulation model of the growth and development of a peanut crop. This version is similar to SOYGRO V5.42, a simulation model of crop growth and development of soybean. They have similar inputs and outputs, similar graphics, and benefits from similar improvements in the code (Wilkerson

et al., 1983; Boote *et al.*, 1985b; 1989; Jones *et al.*, 1989). These two models are part of an international research project funded by IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) project. A major objective of this project is to adopt, develop, and use crop models to study the potential of agricultural production in various soils and climates around the world. IBSNAT (1986) had defined standard input and output formats for climate and soil to make all models in their project more useful with minimal incompatibilities. This standardization allowed the various crop models to be integrated into an overall decision-support system for agrotechnology transfer called DSSAT (Jones, 1986; IBSNAT, 1989).

PNUTGRO V1.02 predicts crop development, dry matter growth (leaves, stems, roots, pods, and seeds), leaf area index (LAI), and final yield of peanut as a function of daily weather data (precipitation, solar radiation, photoperiod, and minimum and maximum temperatures) for specific soils. Soil characteristics and weather data are required inputs. The model is also sensitive to the choice of cultivar, date of planting, spacings between the rows and between the plants, and options for irrigation management. The model, however, does not contain functions to simulate the effect of plant nutrients (nitrogen, potassium, and phosphorus) on plant growth, the effect of calcium on the fruiting process, and the interactions between pests (diseases, insects, nematodes, and weeds) with the peanut crop. Therefore, results from the model should be viewed as potential yields under the specified regimes of weather and soil conditions. Other factors not included in PNUTGRO could be limiting and could further reduce yields.

PNUTGRO also has functions to predict hourly temperatures from the day length, minimum temperature, and maximum temperature of the day. Hourly temperatures are important in the calculation of hourly relative humidities, and functions to compute the relative humidity at each hour were added to the PNUTGRO model.

Prediction of Hourly Relative Humidity

Many fungal pathogens are sensitive to environmental conditions such as humidity patterns and temperature. Leaf wetness is required for germination, infection, and sporulation by the pathogen, but the actual dispersal of air-borne spores occurs when the leaf is dry and the relative humidity of the air is low. Peak catches of spores produced by the early and late leafspot pathogens occur at mid-day when the relative humidity is lower (Alderman *et al.*, 1987; Smith and Crosby, 1973), and wind speed is higher than at night. Thus hourly relative humidities are essential to predict the development of both leafspots. Unfortunately, accurate measurements of relative humidity at each hour are not readily available from weather stations. For this reason, a prediction of relative humidity at each hour from minimum and maximum temperatures would be very useful.

Relative humidity (R_H) is usually obtained from measurements of the dry bulb and wet bulb temperatures. The saturated vapor pressure of the air (e_s) is obtained from the dry bulb temperature (T), and the actual vapor pressure of the air (e_a) is obtained from the wet bulb temperature, which is also called the dew point temperature (T_{dew}). The dew point temperature is usually assumed to be equal to the minimum temperature of the air during the day (Kimball and Bellamy, 1986). The following equations are used to compute relative humidity (Goudriaan, 1982; Sutton *et al.*, 1984; Weiss, 1977):

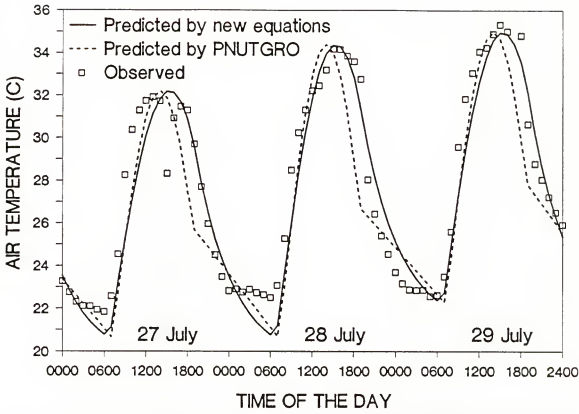


Figure 4-1. Prediction of air temperatures at each hour with functions from PNUTGRO, a peanut growth simulator, and from a modified version of Parton and Logan (1981) functions. Air temperature was observed during July 1988 in Gainesville, Florida.

$$R_H = 100\ (e_a\ /\ e_s)$$

$$e_a = 0.61078\ \exp[17.2693882\ T_{dew}\ /\ (237.3 + T_{dew})]$$

$$e_s = 0.61078\ \exp[17.2693882\ T\ /\ (237.3 + T)]$$

In PNUTGRO, air temperature is predicted at each hour from the day length, minimum temperature, and maximum temperature for use in the calculations for phenological stages. During the day, a sine wave function is used between the time of minimum temperature, estimated at two hours after sunrise and the time of sunset. During the night, a linear decay function is used between the time of sunset and the time of minimum temperature. These functions generate temperatures that closely approximate the air temperature at each hour, but the times of minimum

temperature and maximum temperature are not predicted adequately (Fig. 4-1). Furthermore, the linear decay during the night reduces the smoothness of the curve of air temperature at the points of transition between the sine wave and the linear decay functions.

A modified version of functions proposed by Parton and Logan (1981) was used to reduce the problems mentioned previously (Kimball and Bellamy, 1986). The following functions were used to generate air temperatures that were used to compute relative humidities at each hour:

$$T = (T_{min} - d_m) + [T_{sety} - (T_{min} - d_m)] \exp\left[\frac{-b\ (24 + t - t_{set})}{(24 - D_a + c)}\right]$$

for $0 < t \leq t_{min}$

$$T = T_{min} + (T_{max} - T_{min}) \sin\left[\frac{\pi\ (t - t_{min})}{D_a + 2a}\right]$$

for $t_{min} < t \leq t_{set}$

$$T = (T_{min} - d_e) + [T_{set} - (T_{mint} - d_e)] \exp\left[\frac{-b\ (t - t_{set})}{(24 - D_a + c)}\right]$$

for $t_{set} < t \leq 24$

where: $d_m = (T_{sety} - T_{min}) / [\exp(b) - 1]$

$d_e = (T_{set} - T_{mint}) / [\exp(b) - 1]$

$D_a = t_{set} - t_r$

$t_{min} = t_r + c$

$T_{set} = T_{min} + (T_{max} - T_{min}) \sin\left[\frac{\pi\ (t_{set} - t_{min})}{D_a + 2a}\right]$

Definitions of the variables used in the equations are given in Table 4-2 at the end of this chapter. The prediction of times of minimum temperature and maximum temperature was more accurate with these functions than with the functions of PNUTGRO (Fig. 4-1). Furthermore, the smoothness of the temperature curve at the transition points was improved. These improvements caused a better prediction of the relative humidity at each hour.

Development of Late Leafspot Disease

Conidia produced on crop residue on the soil surface are the main source of initial inoculum. Ascospores, chlamydospores, and mycelial fragments are also potential inoculum sources (Smith, 1984). Spores are disseminated by wind, splashing water, and insects. Wind dissemination is the major vector for spores of *C. personatum.* Peak periods of dispersal for conidia occur at dew dry-off in the morning and at onset of rainfall (Alderman *et al.*, 1987; Mallaiah and Rao, 1980; Smith and Crosby, 1973; Sreeramulu, 1970). Conidia land on peanut leaves, germinate, and penetrate the leaves through the open stomata. Infection usually occurs early in the morning when the leaves are wet and the stomata opened. *Cercosporidium personatum* does not kill host cells in advance like *C. arachidicola*, but produces intercellular botryose haustoria. The pathogen develops in the leaf and the disease becomes visible as necrotic lesions that will produce more conidia to infect other leaf sites.

Spore release at the Site of Inoculum Source

The effects of temperature and relative humidity on the spore release of necrotic lesions at the site of inoculum source have not been documented. Jenkins (1938) determined that ascospores formed in persisting litter are a source of early season inoculum. Shanta (1960) further suggested that mycelia survive in the soil as well as in plant debris from the previous season. Jackson and Bell (1969) indicated that a visible amount of plant debris at the soil surface is not necessary for primary inoculum production. Following the cultural practice of deep and complete burial of surface litter, infection of a second crop of peanut is usually earlier and more extensive than if peanut follows a different crop. Symptoms of leafspot disease were first observed in mid-July of

1986 and 1987 (Chapter 2). The planting date for both years was 2 June. Pixley (1985) also observed first symptoms of leafspot in mid-July, but his planting date was 5 May 1983. If a latent period of 19 to 25 days is assumed, the first infections would have occurred at the end of June. A maturation period or very specific weather conditions may be needed for first sporulation and spore release after the overwintering on crop residues in the soil.

Initial conditions are usually simulated by using the time when the mean disease severity was greater than or equal to 1%, as an input to the model (Knudsen *et al.*, 1987). In the LATESPOT model, the equation of Alderman *et al.* (1987) was used to express the effect of environment on the spore release of *C. personatum* at the site of the inoculum source:

$$f_{ss} = [\exp (0.2968\ T_3 + 0.1123\ N_{R3} - 0.942\ P_{s3} + 0.5517)] \ / \ 10000$$

$$\text{where: } 0 \leq f_{ss} \leq 1$$
$$\text{if } f_{ss} < 0.2, \text{ then } f_{ss} = 0$$

The value of f_{ss} was interpreted as the relative effect of the environment on spore release rather than the absolute number of conidia obtained by Alderman *et al.* (1987). The inputs T_3, N_{R3}, and P_{s3} are the average temperature, the average number of hours of relative humidity over 90%, and the average rainfall, respectively, during the last three days. The equation of Alderman was developed for *C. arachidicola* and was used in our model because a similar equation was not available for *C. personatum*. Even though *C. arachidicola* and *C. personatum* are two different pathogens, they are closely related in their pathogenicity to peanut. One of the problems encountered with the Alderman equation was that production of conidia occurred too early in the growing season. A minimum value of 0.2 for the variable f_{ss} was assumed as a minimum to release spores at the site of inoculum source and subsequent alloinfection at the field site. With

this approach, environmental conditions were first favorable for spore release at the site of inoculum source at the end of June during summer 1986. Data collected in 1986 were used to calibrate the LATESPOT model.

Dissemination

Production and dissemination aof conidia re two different processes, each with their own periodicity. Both periodicities are under the influence of environment. The production of conidia of *C. personatum* requires long periods of high relative humidity or leaf wetness, and high temperatures during these periods. Contrarily, the dissemination process, which includes take-off, flight, and landing, requires periods of low relative humidities when the leaves are dry. After take-off, the conidia are at the grace of air currents and the wind. The flight of the conidia is terminated by their landing on the soil and on plants which can be hosts and non-hosts.

In the LATESPOT model, the dissemination process was simulated simply by a negative exponential function of the distance (d) between the site of inoculum source and the peanut field under study:

$$X_i = f_{ss}\ X_s\ \exp\ (-3\ d/d_{max})$$

A conidial density (X_s) of 100 conidia m^{-3} was arbitrarily assumed at the site of inoculum source. The variable X_i represents the density of conidia that reach the peanut field under study from the site of inoculum source. The total density of conidia at the field site (X_c) is the sum of X_i and X_p, where X_p is the density of conidia produced by infectious lesions in the peanut canopy after the initial cycle of disease development. All the conidia are then affected by a mortality factor under long periods of relative humidity below 40% (Alderman and Beute, 1986) and by movement or

flight out of the peanut field. The remaining conidia land on peanut leaves and infect them if environmental conditions are favorable. Conidia that do not infect peanut leaves on a given day are considered lost and non-infective on the next day. The proportions of the conidial population that landed on the soil and on non-host tissues were assumed not to be reentrant.

Infection of Peanut Leaves

The infection of peanut leaves by *C. personatum* depends on many factors. After landing on peanut leaves, the conidia germinate by forming one to several germ tubes which grow over the leaf surface and through open stomata. Penetration may also occur directly through the lateral faces of epidermal cells (Jackson and Bell, 1969). Temperatures of 16 to 20°C are very favorable for germination of conidia of *C. personatum* placed in small moist chambers to maintain high humidity (Sommartya and Beute, 1986). Constant exposure to 20 or 24°C is very favorable for infection of peanut leaves by *C. personatum* after exposure to high relative humidity for at least 12 h d^{-1} in an infection period of six days (Shew *et al.*, 1988). According to these results, it is likely that infection occurs early in the morning close to sunrise when the air temperature is low, relative humidity is high, and the stomata are opening.

The genetics of the pathogen and the host also needs to be considered in the infection process. Alderman and Beute (1986) observed an infection efficiency of 85% for *C. arachidicola* under prolonged favorable conditions. This infection efficiency may differ between species and between pathogen races. Similarly, the host varies in its susceptibility to a given pathogen. Peanut cultivars were characterized as having high partial, moderate, and very low resistances to *C. personatum* (Shew *et al.*,

1988). The differential susceptibility to infection between leaves of different cultivars is due to factors that limit the growth of the pathogen within the leaf; the number of successful stomatal penetrations of the host by the pathogen is always greater than the resulting number of leafspots (Cook, 1981). Resistance may also occur in a leaf of a susceptible cultivar. Luke *et al*. (1984), in their work with crown rust on oats, believed that almost all host mesophyll cells are capable of response to the pathogen, but some cells in a given leaf are more sensitive than others. Some sites on a given leaf of a susceptible cultivar may be more or less resistant to invasion by the pathogen.

In the LATESPOT model, the infection by the pathogen (I) was expressed as a function of 1) the effect of the environment (f_i), 2) the density of conidia at the field site (X_c), 3) the probability that a conidia will penetrate a vacant susceptible leaf site (P_i), and 4) the infection efficiency of the conidia (e_i):

$$I = (f_i \; X_c \; P_i \; e_i)/n_{ls}$$

where: $P_i = f_g \; f_a$

The variable f_g is the factor of the Gregory multiple transformation and f_a is the factor of the physiological leaf age. The parameter n_{ls} is the number of leaf sites per unit leaf area. The effect of the environment on the infection by *C. personatum* was derived from results obtained by Shew *et al*. (1988). Multiple regression was used to develop a function that closely approximated (R^2=90%) the influence of temperature (T_i) and length of daily exposure to relative humidity over 93% (N_{Ri}) on infection of peanut leaves by *C. personatum*:

$$f_i = 0.2477 + 0.1548 \; N_{Ri} - 0.0134 \; T_i - 0.0036 \; N_{Ri} \; T_i - 0.0015 \; N_{Ri}^2$$

where: $0 \leq f_i \leq 1$; if $T_i \leq 16$ or $N_{Ri} < 3$, then $f_i = 0$

Knudsen *et al.* (1987) used the Jensen and Boyle (1966) model to simulate the infection process. In the early versions of the LATESPOT model, the Jenson and Boyle model was included but their model did not adequately simulate the infections of peanut leaves by *C. personatum*. The model developed by Knudsen *et al.* (1987) was calibrated and validated with data collected in peanut fields where *C. arachidicola* was the predominant pathogen.

When environmental conditions are favorable for infection, the pathogen has then the capability of penetrating susceptible leaf sites of the host. The host is thought to consist of a large but finite number of susceptible leaf sites or infection sites. All infection sites have equal areas and equal chances of infection (Zadoks, 1971). In our model, a leaf site is equivalent to the area affected by one reproductive unit of the pathogen. We assumed that a conidia of 50 μm long (Smith, 1984) will affect an area of 2500 μm^2. The number of leaf sites per unit leaf area (n_{ls}) resulting from this assumption is 40000 leaf sites per cm^2. Leaf sites become susceptible to *C. personatum* after approximately a week from leaf emergence:

$$f_a = [1 + 9999 \exp(-1.32\ P_a)]^{-1}$$

Time after leaf emergence (P_a) is expressed in physiological days, which is equivalent to actual days if the temperature is optimum for 24 hours per day. Furthermore, a maximum of 50% of the leaf sites are assumed to be susceptible to infection by the pathogen (s_r). The last step in expressing the relation between the pathogen and the host during the infection process, is to determine the probability that the conidia will penetrate a vacant susceptible leaf site. It is well recognized in plant epidemiology that a pathogen will not infect a leaf site already infected

(Freedman and MacKenzie, 1987). As the percentage of infected leaf sites increases, the probability that each additional conidia falls on a leaf site already infected also increases, and these conidia produce no increase in percentage of leaf sites infected. (Gregory, 1948). These "second attempts" are referred to as multiple infections (Vanderplank, 1963). The multiple-infection transformation of Gregory (Gregory, 1948; Zadoks and Schein, 1979) was used in our model to simulate this concept:

$$f_g = c_g / -\ln (1 - S_{os}) \qquad (0 \leq f_g \leq 1;\ 0 \leq S_{os} \leq 1)$$

The frequency distribution of multiple-infection follows the Poisson distribution (Gregory, 1948; Zadoks and Schein, 1979). The variable S_{os} is the fraction of susceptible leaf sites occupied by the pathogen. The constant c_g was obtained from preliminary testings of the LATESPOT model. Sensitivity analyses on this constant are discussed in Chapter 5.

Pathogen Development in the Leaf

After infection of the leaf sites, the pathogen continues to develop inside the leaf. At this point, it becomes more difficult to quantify the pathogen as a unit or a leaf site. It is more convenient to quantify it as the leaf area occupied by the pathogen at different developmental stages. The leaf area of the host occurs under one of the following mutually exclusive conditions: vacant, latently infected (A_{LAT}), pre-infectious (A_{PRE}), infectious (A_{INF}), and post-infectious (A_{POS}) (Fig. 4-2). These conditions were defined as the developmental stages of the pathogen in the LATESPOT model. Differential equations describing the rates of change of these state variables are given in Table 4-1. The vacant leaf area becomes latently infected after the infection process. The pathogen is present in the leaf but no symptoms are visible. After a period of time, defined as the incubation period (i_c), necrotic lesions occur on the

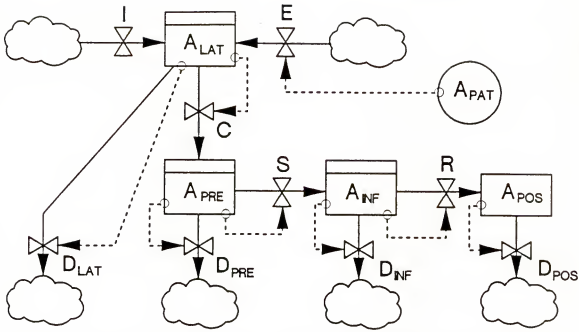


Figure 4-2. Forrester diagram of the LATESPOT model. Differential equations describing the rates of change of state variables are given in Table 4-1 and variables are defined in Table 4-2.

leaf but these lesions are not sporulating. This condition is referred to as the pre-infectious leaf area. The incubation period is approximately 10 days for *C. personatum* on Florunner peanut (Chiteka, 1987; Chiteka *et al.*, 1988). The rate of development between the latently infected state to the pre-infectious state was called the colonization rate (C).

One of the most important parameters in plant epidemiology is the latent period which is defined as the time between exposure or inoculation of the pathogen until apparition of signs of the disease. For late leafspot, such signs are the conidia produced on the necrotic lesions. At this point in the development of the pathogen, the leaf area is referred to as infectious. Conidia on necrotic lesions occur between 18 to 32 days after exposure or inoculation of *C. personatum* on Florunner peanut (Chiteka, 1987; Chiteka *et al.*, 1988; Shew *et al.*, 1988; Walls *et*

Table 4-1. Differential equations describing the rates of change of the state variables in the LATESPOT model.

Latently infected leaf area

$$\frac{dA_{LAT(1)}}{dt} = I + E - C_1 - D_{LAT(1)}$$

$$\frac{dA_{LAT(j)}}{dt} = C_{j-1} - C_j - D_{LAT(j)} \qquad \text{where } j=2,\ldots,i_c$$

Pre-infectious leaf area

$$\frac{dA_{PRE(1)}}{dt} = C_j - S_1 - D_{PRE(1)} \qquad \text{where } j=i_c$$

$$\frac{dA_{PRE(k)}}{dt} = S_{k-1} - S_k - D_{PRE(k)} \qquad \text{where } k=2,\ldots,\rho_1-i_c$$

Infectious leaf area

$$\frac{dA_{INF(1)}}{dt} = S_k - R_1 - D_{INF(1)} \qquad \text{where } k=\rho_1-i_c$$

$$\frac{dA_{INF(m)}}{dt} = R_{m-1} - R_m - D_{INF(m)} \qquad \text{where } m=2,\ldots,i_1$$

Post-infectious leaf area

$$\frac{dA_{POS}}{dt} = R_m - D_{POS} \qquad \text{where } m=i_1$$

al., 1985; Watson, 1987). The latent period from infection until 50% of the necrotic lesions are sporulating (ρ_{50}) is approximately 25 days. In the LATESPOT model the latent period is equal to the sum of the incubation period and the maturation period, which was defined as the time between the apparition of the necrotic lesions and the apparition of conidia on the necrotic lesions. The rate of development between the pre-infectious

state and the infectious state was called the production rate of sporulating area (S).

As suggested previously, when a population of infections occurs on a given day, the sporulating lesions developing from these infections do not all appear on the same day one latent period later. For late leafspot, the apparition of sporulating lesions on susceptible cultivars of peanut ranges between 18 and 32 days when the inoculation was done on a given day. In the LATESPOT model, a distributed-delay function was used to generate a distribution of stage-completion times (Berger and Jones, 1985; Curry and Feldman, 1987; Ferrari, 1978; 1982; Jones *et al.*, 1987; Manetsch, 1976). With a distributed-delay function, the infections flow through a series of substages, and they emerge as a distribution of developing times. This distribution is described by the Erlang density function (Curry and Feldman, 1987; Manetsch, 1976). The number of substages (n) in the delay chain can be estimated from the mean development time (μ) and the variance of the development time (σ^2):

$$n = \mu^2/\sigma^2 = \rho_{50}{}^2/s^2$$

In the LATESPOT model, we assumed that μ was equivalent to the ρ_{50} of late leafspot on Florunner peanut and that s = 5.75. The number of substages estimated was 19 which corresponds to the time from inoculation to the apparition of the first sporulating lesions (ρ_1) in the LATESPOT model. All development rates between substages were the same and were also a function of the average temperature during the day (f_T):

$$C_j = A_{LAT(j)}(\rho_1 \,/\, \rho_{50})\ f_T \qquad (j=1, i_c)$$
$$S_k = A_{PRE(k)}(\rho_1 \,/\, \rho_{50})\ f_T \qquad (k=1, \rho_1 - i_c)$$

Many workers have reported the influence of temperature on the length of the latent period. Knudsen *et al.* (1987) made the simplifying

assumption that the relationship is linear with a latent period of 10 days at 22°C and 21 days at 19°C for early leafspot. It is difficult to imagine that a 3°C difference in temperature causes a doubling in the latent period. Shew *et al.* (1988) observed that ρ_1 was the shortest at 24°C for genotypes with very low resistance to the late leafspot pathogen. Temperature of 20 and 28°C resulted in a delay of three to four days in ρ_1 for these same genotypes. There was no sporulation at 32°C on any genotypes by 32 days after inoculation. Alderman and Beute (1987) observed the effect of temperature on sporulation of *C. arachidicola*. Conidial production increased from 16 to 24°C and declined sharply between 28 and 32°C. In the LATESPOT model, the following equation is used to express the effect of temperature (T) on pathogen development in the leaf:

$$f_T = \cos [0.1339 (T - T_o)] \qquad (0 \leq f_T \leq 1)$$

This function is based on observations by Shew *et al.* (1988) on two susceptible cultivars of peanut. The optimum temperature (T_o) was 24°C. Furthermore, this function approximates almost perfectly the relative effect of temperature on radial growth of *Cercospora zebrina* Pass. grown on potato-dextrose agar (Berger and Hanson, 1963). *C. zebrina* attacks clovers (*Trifolium* species). Once the fungus is inside the leaf, its growth would additionally be regulated by internal leaf water potentials. The water status of the leaf was assumed not to be a limiting factor because the plants were well-watered.

In this section, the development of the pathogen through its developmental stages was discussed. However, the pathogen does not only develop through its life stages, it also grows radially inside the leaf and invades neighboring tissue. This process was observed by many workers and is commonly reported as the lesion expansion, a significant component

of disease progress (Berger and Jones, 1985). In the LATESPOT model, we assumed that lesion expansion is a consequence of the expansion of the infected leaf area (Fig. 4-2). The infected leaf area (A_{PAT}) is the leaf area occupied by the pathogen, and the diseased leaf area (A_{DIS}) is the leaf area showing symptoms (necrotic lesions) of the disease:

$$A_{PAT} = \Sigma A_{LAT(j)} + \Sigma A_{PRE(k)} + \Sigma A_{INF(m)} + A_{POS}$$
$$A_{DIS} = \Sigma A_{PRE(k)} + \Sigma A_{INF(m)} + A_{POS}$$

The expansion rate of the infected leaf area (E) was assumed to be equal to the colonization rate and the production rate of sporulating area between the substages of the distributed delay. Since the relation between the expansion rate and the development rates was not known, we added a correction factor (f_E) to calibrate the LATESPOT model:

$$E = A_{PAT}(\rho_1 \ / \ \rho_{50}) \ f_T \ f_E$$

Sensitivity analyses on the parameter f_E are discussed in Chapter 5.

Spore Release from Infectious Lesions

The infection cycle is composed of two major periods, the latent period (ρ) and the infectious period (i). As with the latent period, i_1 was defined as the time from first production of spores to first spore release from the infectious lesions, and i_{50} as the time from first production of spores to 50% of the spores released from the infectious lesions. The infectious period consists of two distinct events that occur simultaneously: spore release and removal of infectious leaf area. For each unit of infectious leaf area that is removed, there is a corresponding number of spores that are released. The transition from the infectious leaf area to the post-infectious leaf area is called removal (Zadoks and Schein, 1979), and is distributed over time. In the LATESPOT model, we used another distributed-delay function to simulate this

distribution over time. Information on the infectious period is scarce or imprecise in the literature. For early leafspot, Knudsen *et al.* (1987) used $i_1 = 2$ and $i_{50} = 8$ to simulate the removal rate of infectious leaf area. In the LATESPOT model, we assumed that $i_1 = 2$ and $i_{50} = 5$ based on information provided by Nutter (personal communication) for late leafspot. The removal rate of infectious leaf area (R) is computed with the following equation:

$$R_m = A_{INF(m)}(i_1 / i_{50}) f_{sf} \qquad (m=1, i_1)$$

The variable f_{sf} is obtained from the equation of Alderman *et al.* (1987), as described previously, and represents the relative effect of the environment on the removal rate at the field site under study:

$$f_{sf} = [\exp (0.2968 T_3 + 0.1123 N_{R3} - 0.942 P_{f3} + 0.5517)] / 10000$$

where: $0 \leq f_{sf} \leq 1$

The inputs T_3, N_{R3}, and P_{f3} are the average temperature, the average number of hours of relative humidity over 90%, and the average precipitation (rainfall and irrigation), respectively, during the last three days. The removal rate of infectious leaf area is multiplied by the number of conidia produced by unit of infectious leaf area (c_p) to obtain the corresponding number of conidia that are released. Watson (1987) estimated that approximately 250 conidia of *C. personatum* were produced per mm^2 of infectious leaf area on the peanut cultivar Florunner. This value was used in the LATESPOT model to compute the number of conidia released daily from the sporulating necrotic lesions.

Effect of Late Leafspot on Peanut Growth

Leaf Cohort Approach

Late leafspot progresses gradually from the bottom to the top of the peanut canopy (Pixley, 1985; Plaut and Berger, 1980; Chapter 2). Older

leaves defoliate earlier than younger leaves. The peanut leaves in the canopy can be divided in many leaf cohorts, which are groups of leaves of the same age. In the LATESPOT model, there is a leaf cohort for each day, and the late leafspot disease progresses independently on each leaf cohort. The crop attributes included in each leaf cohort are the leaf weight, the leaf area, the specific leaf area (leaf area per unit of leaf dry weight), and the physiological age of the leaf.

Photosynthesis and Defoliation

The effect of late leafspot first occurs on peanut leaflets. Necrotic lesions are produced by the pathogen and reduce the photosynthetic efficiency of infected leaflets (Chapter 3). A few days after the apparition of necrotic lesions, the leaflets abscise and the total leaf area of the peanut canopy is reduced. At the canopy level, the loss of leaflets is the major factor causing reductions in total canopy photosynthesis. Necrotic lesions on the remaining leaflets represent not more than 10% of the total leaf area that is not defoliated (Chapters 2 and 3). Boote *et al.* (1983) mentioned a toxic effect on the photosynthetic mechanism of the remaining leaves. According to the results obtained in the previous chapters, this effect on photosynthesis may be significant at the leaflet level, but is probably very negligible at the canopy level compared to the loss of leaf area by acceleration of defoliation and by reduction of healthy leaf area due to necrotic lesions. The effect of late leafspot on peanut growth was simulated in the LATESPOT model by reductions in leaf area index due to disease-induced defoliation, and due to the presence of necrotic lesions on the leaves (loss of healthy leaf area).

A leaf cohort is composed of a population of leaflets, and all leaflets in the leaf cohort are not defoliated at the same time. This population of leaflets was assumed to have a mean and a variance for their infected leaf area. If a given percentage of infected leaf area is selected as a reference to trigger defoliation, some leaflets will abscise when the mean infected leaf area is lower than the reference, and more leaflets will abscise when the mean is higher than the reference. In the LATESPOT model, the disease-induced defoliation was assumed to increase exponentially with the fraction of infected leaf area, which is the leaf area occupied by the pathogen (Fig. 4-3). Defoliation occurs independently for each cohort. Defoliation was assumed to begin at a minimum threshold (D_m) of the fraction of infected leaf area, and to be maximum threshold (D_x) of the fraction of infected leaf area. Furthermore, a factor (D_h) was included to account for different rates of defoliation between healthy, latently infected, and diseased leaf areas. The rates of defoliation of healthy and latently infected leaf areas were assumed to be lower than the rate of defoliation of diseased leaf area.

Reduction in light interception due to the presence of necrotic lesions was simulated by using healthy leaf area index in the photosynthetic rate equation of the peanut growth simulator, PNUTGRO. Disease-induced defoliation causes a loss of the whole leaf. In PNUTGRO, the leaf is composed of two parts: the leaf blade and the petiole. The petiole is included in the stem fraction. Furthermore, each of them has a protein fraction that is remobilized to the reproductive organs during the senescence process of the plant. Reductions in leaf weight, stem weight, and protein weight in the leaf and in the stem are part of the events associated with disease-induced defoliation. Protein mobilization

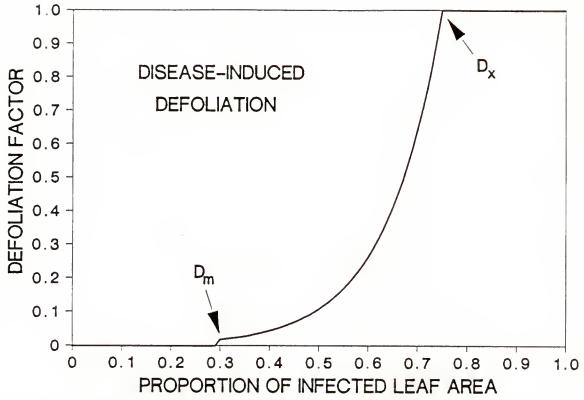


Figure 4-3. Defoliation factor as a function of the proportion of the leaf area that is infected in a leaf cohort. The infected leaf area is defined as the leaf area occupied by the pathogen.

occurs normally as a function of leaf age, but when abscision is early due to leafspot, part of the mobilizable protein is lost with the abscised leaflets.

Pod Losses

Pod losses, close to harvest time, are also more important after complete defoliation of the peanut canopy (Chapter 2). The problem is presently under investigation (Shokes, personal communication) to understand the interactions between the plant, the environment, and the pathogens involved in pod losses. At this point, it seems that *C. personatum* is only secondarily involved in peg deterioration, which is believed to be the major cause of pod losses in the peanut fields of

Florida. The LATESPOT model does not include functions to simulate reductions in pod weight and number, and seed weight and number. So, simulation results must be interpreted as potential values, and can be verified by retrieving abscised pods from the soil.

Graphics and Sensitivity Analysis Options

The interface between the PNUTGRO model and the user was slightly modified with the coupling of the LATESPOT model to include graphical access to epidemiological parameters of interest and to facilitate sensitivity analyses on input values. For sensitivity analyses, a pseudo-pathogen race selection was defined, and could be modified easily with a simple text editor. Options to access sensitivity analyses were already available in PNUTGRO. Furthermore, an option was added to the graphics program to obtain a graphical display of leaf area in each state described previously, plus the percent infection, percent disease, percent defoliation, disease severity, density of conidia in the peanut canopy, and effect of environment on infection, spore release, and pathogen growth. Both PNUTGRO and LATESPOT are written in FORTRAN and the graphics program is written in BASIC. Input and output formats follow the standards defined by IBSNAT (1986). A compiled version of all programs and data sets can be obtained from the author. The FORTRAN code of the LATESPOT model is given in Appendix D, and the variables in the computer program are defined in Appendix E. A few subroutines and the input files for treatment management of the original PNUTGRO V1.02 model were modified to couple the LATESPOT model. These changes are indicated in Appendix F.

Conclusion

Simulation techniques offer an alternative to analytical models in modeling the behavior of complex systems. Both PNUTGRO V1.02 and LATESPOT

are simulation models that contain series of simple equations that express mathematically many biological processes. In this chapter, the LATESPOT model was described in detail. The model includes functions for dissemination of conidia, infection of leaf tissues by germ tubes from conidia, disease development in the leaf which includes expansion, colonization, and sporulation, and spore release from infectious lesions. All these processes are affected by daily environmental conditions. Furthermore, the interaction between the pathogen and the host was described. Two major effects are represented mathematically: 1) reduction of canopy photosynthesis due to disease-induced defoliation and 2) reduction of light interception due to the presence of necrotic lesions on the leaves. The latter also reduces the canopy photosynthesis.

Even though the LATESPOT model contains many details about the epidemiology of late leafspot on Florunner peanut, many assumptions were made and research is needed to improve our knowledge of the pathosystem. The evaluation of the LATESPOT model in Chapter 5 will highlight some of the most important concepts that need more information. The LATESPOT model was developed to simulate disease progress on Florunner peanut. It can possibly be used for other cultivars that are susceptible to late leafspot. Modifications in the genetic coefficients of PNUTGRO will be needed to simulate the effect of late leafspot on peanut cultivars that have partial and high resistance to late leafspot. According to preliminary results obtained from LATESPOT, the latent period and the number of conidia per unit of infectious leaf area should be the major components of resistance between peanut cultivars. This agrees with experimental results obtained on resistant cultivars by other workers (Chiteka, 1987; Chiteka *et al.*, 1988; Shokes, personal communication;

Watson, 1987). These two parameters may also be involved in the difference between the characteristics of early and late leafspot, and the two diseases would be expected to react differently to various environmental conditions. Genetic differences in peg strength have also been observed between cultivars. Peg deterioration is believed to be a major cause of pod losses at harvest. Neither PNUTGRO nor LATESPOT simulate pod abscission which is accelerated close to harvest after complete defoliation of the peanut canopy. More information is needed to describe mathematically this biological process which may involve interactions between the plant, the soil environment, and saprophytic organisms.

Table 4-2. Definition of variables used in the equations described in Chapter 4.

Variable	Definition [units]
a	Parton and Logan (1981) constant a; Time lag in maximum temperature after noon [h] -- (a = 1.86).
A_{DIS}	Total diseased leaf area [$cm^2\ m^{-2}$].
A_{INF}	Infectious leaf area [$cm^2\ m^{-2}$].
A_{LAT}	Latently infected leaf area [$cm^2\ m^{-2}$].
A_{PAT}	Total infected leaf area [$cm^2\ m^{-2}$].
A_{POS}	Post-infectious leaf area [$cm^2\ m^{-2}$].
A_{PRE}	Pre-infectious leaf area [$cm^2\ m^{-2}$].
A_{TOT}	Total leaf area [$cm^2\ m^{-2}$].
b	Parton and Logan (1981) constant b; Coefficient that controls temperature decrease at night -- (b = 2.20).
c	Parton and Logan (1981) constant c; Time lag for the minimum temperature after sunrise [h] -- (c = 1.50).
c_g	Constant in the function used to compute the Gregory multiple transformation factor -- (c_g = 0.01).
c_p	Number of conidia produced by unit area of a sporulating lesion [conidia cm^{-2}] -- (c_p = 25000).
C	Colonization rate; Transformation of latently infected leaf area into pre-infectious leaf area [$cm^2\ m^{-2}\ d^{-1}$].
C_j	Colonization rate substage j in the distributed delay [$cm^2\ m^{-2}\ d^{-1}$].
d	Distance between the field site under study and the site of inoculum source [m].
d_e	Displacement factor (Kimball and Bellamy, 1986) for the evening between sunset and midnight [°C].
d_m	Displacement factor (Kimball and Bellamy, 1986) for the morning between midnight and time of minimum temperature [°C].
d_{max}	Maximum distance for conidia dissemination [m] -- (d_{max} = 10000).
D_a	Astronomical daylength [h].
D_h	Disease-induced defoliation factor of healthy leaf tissue -- (D_h = 0.68).
D_{INF}	Defoliation rate of infectious leaf area [$cm^2\ m^{-2}\ d^{-1}$].
D_m	Proportion of infected leaf area at which minimum disease-induced defoliation occurs; No disease-induced defoliation occurs below this value -- (D_m = 0.30).
D_{LAT}	Defoliation rate of latently infected leaf area [$cm^2\ m^{-2}\ d^{-1}$].
D_{POS}	Defoliation rate of post-infectious leaf area [$cm^2\ m^{-2}\ d^{-1}$].
D_{PRE}	Defoliation rate of pre-infectious leaf area [$cm^2\ m^{-2}\ d^{-1}$].
D_x	Proportion of infected leaf area at which maximum disease-induced defoliation occurs -- (D_x = 0.75).

Table 4-2 -- continued.

Variable	Definition [units]
e_i	Infection efficiency of conidia under optimal conditions -- (e_i = 0.85).
E	Expansion rate of the infected leaf area [$cm^2\ m^{-2}\ d^{-1}$].
f_a	Factor of the physiological leaf age.
f_E	Expansion factor of the infected leaf area -- (f_E = 1.10).
f_g	Gregory multiple transformation factor.
f_i	Factor expressing the effect of environment on the infection of the leaves by the pathogen.
f_{sf}	Factor expressing the effect of environment on spore release by the pathogen at the field site under study.
f_{ss}	Factor expressing the effect of environment on spore release by the pathogen at the site of inoculum source.
f_T	Temperature factor for pathogen development in the leaf.
i_1	Infectious period to first spores removed from the sporulating lesions [d] -- (i_1 = 2).
i_{50}	Infectious period to 50% of the spores removed from the sporulating lesions [d] -- (i_{50} = 5).
i_c	Incubation period to apparition of first necrotic lesions [d] -- (i_c = 10).
I	Infection rate on healthy leaf area [$cm^2\ m^{-2}\ d^{-1}$].
n	Number of substages in a distributed-delay function.
n_{ls}	Number of leaf sites per unit of leaf area [sites cm^{-2}] -- (n_{ls} = 40000).
N_{R3}	Average number of successive hours of relative humidity over 90% during the last three days [h].
N_{Ri}	Number of successive hours of relative humidity over 93% during the actual day [h].
P_a	Physiological age of the leaf [d].
P_i	Probability that a conidium will penetrate a vacant susceptible leaf site under optimal conditions.
P_{f3}	Average precipitation (rain and irrigation) for spore release at the field site under study during the last three days [cm].
P_{s3}	Average rainfall for spore release at the site of inoculum source during the last three days [cm].
R	Removal rate; Transformation of infectious leaf area into post-infectious leaf area [$cm^2\ m^{-2}\ d^{-1}$].
R_H	Relative humidity of the air [%].
s	Standard deviation of the development time of a distributed-delay function.
s_r	Fraction of the total leaf area that is susceptible to infection by the pathogen -- (s_r = 0.50).

Table 4-2 -- continued.

Variable	Definition [units]
S	Production rate of sporulating area; Transformation of pre-infectious leaf area into infectious leaf area [$cm^2\ m^{-2}\ d^{-1}$].
S_k	Production rate of sporulating area of substage k in the distributed delay [$cm^2\ m^{-2}\ d^{-1}$].
S_{os}	Fraction of susceptible leaf sites occupied by the pathogen.
t	Time of the day [h].
t_{min}	Time when the minimum air temperature occurs during the day [h].
t_r	Hour of sunrise each day [h]
t_{set}	Hour of sunset each day [h].
T	Air temperature at time t [°C].
T_3	Average temperature of the air for spore release during the last three days [°C].
T_a	Average temperature of the air during the day [°C].
T_{dew}	Dew point temperature of the air [°C].
T_i	Average temperature for infection during period of relative humidity over 93% [°C].
T_{max}	Daily maximum air temperature [°C].
T_{min}	Daily minimum air temperature [°C].
T_{mint}	Minimum air temperature of tomorrow [°C].
T_{set}	Air temperature at sunset [°C].
T_{sety}	Air temperature at sunset of yesterday [°C].
X_c	Number of conidia in the peanut canopy at the field site under study [m^{-3}].
X_i	Number of conidia that are disseminated from the site of inoculum source [m^{-3}].
X_p	Number of conidia removed from the infectious leaf area of all leaf cohorts [m^{-3}].
X_s	Maximum number of conidia that can be disseminated from the site of inoculum source [m^{-3}] -- ($X_s = 100$).
e_a	Actual vapor pressure of the air; based on dew point temperature [kPa].
e_s	Saturated vapor pressure of the air at dry bulb temperature [kPa].
μ	Mean development time of a distributed-delay function.
σ^2	Variance of the development time of a distributed-delay function.
π	Constant which is equal to 3.141593.
ρ_1	Latent period to first lesions showing sporulation [d] -- ($\rho_1 = 19$).
ρ_{50}	Latent period to 50% of the lesions showing sporulation [d] -- ($\rho_{50} = 25$).
T_o	Optimum air temperature for pathogen development [°C] -- ($T_o = 24$).

CHAPTER 5

SIMULATION MODEL OF LATE LEAFSPOT AFFECTING PEANUT: II. CALIBRATION, VALIDATION, AND SENSITIVITY ANALYSES

Peanut, *Arachis hypogaea* L., is a crop grown on over 18,000,000 ha throughout the world. Wherever peanut is grown, the major foliar diseases affecting peanut are early leafspot, induced by *Cercospora arachidicola* Hori, and late leafspot, induced by *Cercosporidium personatum* (Berk. & Curt.) Deighton. In Florida, late leafspot is the predominant disease affecting peanut. LATESPOT, a simulation model of late leafspot progression on peanut leaves was developed and coupled to PNUTGRO V1.02, a simulation model of peanut growth and development. PNUTGRO was developed to simulate the growth and yield of Florunner peanut in response to environment, genotype, and management conditions (Boote *et al.*, 1988). The LATESPOT model was coupled to the PNUTGRO model to help the understanding of this pathosystem, to determine the effect of the pathogen on crop growth, and to predict yield reductions due to late leafspot.

The implementation of a simulation model involves many steps as described by Jones *et al.* (1987). After the conceptualization of the model and its translation into computer code, the simulation model needs to be evaluated for its capacity to simulate the behavior of the real system. Procedures included in this evaluation are verification, calibration, validation, and sensitivity analyses. "The verification involves the evaluation of the accuracy with which the computer code

represents the model" (Jones *et al.*, 1987). In this procedure, the logic of the computer code is compared with the description of the model which was illustrated with either flow charts, mathematical equations, or both. "Calibration refers to quantifying parameters in the model using system observations and the simulation outputs" (Jones *et al.*, 1987). Adjustments are made to model parameters to give the most accurate comparison between simulated results and results obtained from field measurements. This procedure, as well as the validation procedure, involves the collection of field data required to compare model predictions with the real system. "Validation is the process of comparing simulated results to real system data not previously used in calibration or in any parameter estimation process" (Jones *et al.*, 1987). In the validation procedure, the simulation model can be tested for other environmental conditions or other management conditions depending on field data available. The adaptability of a simulation model to different conditions is an important criteria for future applications. Finally, "sensitivity analysis is the process by which parameters or inputs are evaluated with regard to their importance relative to simulation results" (Jones *et al.*, 1987). The model is sensitive to a parameter if a major change in the output occurs when the parameter is changed. Sensitivity analysis can be conducted at many levels of the model development. It can be used in the verification process to evaluate extreme values of parameters which will test the logic and stability of the model. During the calibration, sensitivity analyses are useful to determine which parameters are the most sensitive and to evaluate their effect on output variables of interest. Also, the most sensitive parameters then need the most accurate measurement. After validation, sensitivity analyses can be

used to answer "what if" questions, to develop management strategies, and to determine important subsystems, relationships, and inputs.

One of the objectives of this research was to evaluate the PNUTGRO-LATESPOT model under environmental conditions of Florida. Measurements of plant growth and estimates of disease intensity collected in 1986 were used to estimate parameters and calibrate the PNUTGRO-LATESPOT model. Measurements of plant growth and estimates of disease intensity collected in 1983, 1985, and 1987 were used to validate the model. The four years represented a range of planting dates (5 May 1983, 2 June 1986, 2 June 1987, and 17 June 1985) and locations in Florida (1983: Marianna, 1985: Agronomy Farm of Green Acres in Gainesville, and 1986-1987: Agronomy Farm of the University of Florida in Gainesville). In the evaluation of the model, sensitivity analyses were included to examine the behavior of the model when parameters were changed. Results of this evaluation are presented in this chapter.

Materials and Methods

Measurements of plant growth and estimates of disease intensity from 1986 and 1987 were obtained from an experiment conducted at the Agronomy Farm of the University of Florida in Gainesville. Florunner peanut was planted on 2 June of both years at a rate of 20 seeds m^{-2} in rows 0.91 m apart to achieve a population of 13 to 14 plants m^{-2}. The soil type was a fine sand (loamy, siliceous, hyperthermic Grossarenic Paleudult). Field operations for 1986 and 1987 are detailed in Tables A-1 and A-2, respectively. Irrigation with overhead sprinklers provided water to the field when needed. Weather conditions (solar radiation, rainfall, and maximum and minimum temperatures) were monitored at the Official Weather Station of the Agronomy Farm located approximately 1000 m from the peanut

field. The experimental design was a completely randomized block with two treatments: 1) fungicide treated and 2) not treated, and four replications. The fungicide chlorothalonil was used at a rate of 2.3 l ha^{-1}. Applications of fungicide began 32 and 23 days after planting in 1986 and 1987, respectively. Time between applications was between 8 and 12 days, and sprays were applied until the first week of October.

To obtain additional sets of data for validation, measurements of plant growth and estimates of disease intensity from 1983 and 1985 were obtained from Pixley (1985) and Pixley (unpublished), respectively. Field experiments were conducted at Marianna, Florida, during summer 1983, and at the Agronomy Farm of Green Acres in Gainesville, Florida, during summer 1985. Florunner peanut was planted densely on 5 May 1983, and on 17 June 1985 in rows 0.91 m apart. Seedling stands were manually thinned to a density of 11 plants m^{-2} shortly after emergence. The soil types at Marianna and at the Green Acres Farm were a fine-sandy loam (siliceous, thermic Typic Paleudult) and a fine sand (loamy, siliceous, hyperthermic Grossarenic Paleudult), respectively. Conventional field operations to grow peanut were applied (Pixley, 1985). Plots were irrigated using a center pivot system at Marianna and overhead sprinklers at Gainesville. Rainfall, and minimum and maximum temperatures were monitored in Marianna, and only rainfall was monitored at the Green Acres Farm in Gainesville. Other weather parameters needed to run the simulation model were obtained from the Official Weather Station of the Agronomy Farm in Gainesville. At both locations, the experimental design was a randomized complete block split-plot with four replications. The two main plot treatments were 1) fungicide treated and 2) not treated. The fungicide treatment consisted of bi-weekly applications of chlorothalonil (3.4 l ha^{-1}) plus

flowable sulfur (2.3 l ha^{-1}). Peanut genotypes were the sub-plot treatments. Only the Florunner cultivar was used to evaluate the simulation model.

Growth Analysis and Disease Assessment

In 1986 and 1987, measurements for growth analysis and disease assessment were done weekly on the peanut crop to obtain data needed for comparison with values predicted by the simulation model (Table 5-1). Growth analysis and disease assessment were described in Chapters 2 and 3. In 1983 and 1985, Pixley (1983; unpublished) made observations and measurements periodically (10-day intervals in 1983 and 14-day intervals in 1985) and these measurements were used to evaluate some values predicted by the simulation model (Table 5-1). Disease was assessed as in Chapters 2 and 3, except that percent necrotic leaf tissue in three layers of the crop canopy was assessed with the aid of a modified Horsfall-Barratt (1945) standard area diagram (Nevill and Littrell, 1982).

Evaluation of PNUTGRO and LATESPOT

Measurements of plant growth and estimates of disease intensity obtained from these four years were used to evaluate both PNUTGRO and LATESPOT. PNUTGRO was calibrated for the four years with measurements obtained from the fungicide-treated plots. Genetic coefficients of the cultivar Florunner were modified for each individual year according to a procedure to estimate genetic coefficients for a new cultivar (Boote *et al.*, 1989). To evaluate the performance of LATESPOT, an accurate prediction by PNUTGRO without the effect of late leafspot was necessary. The goal here was not to validate PNUTGRO, but to validate LATESPOT. The PNUTGRO-LATESPOT model was calibrated with field data obtained during

Table 5-1. Growth stages, components of growth analysis, and disease assessment for the evaluation of PNUTGRO and LATESPOT. Field data were obtained from experiments conducted during summers of 1983, 1985, 1986, and 1987 in Florida.

Predicted by the Simulation Model	Units	Observed in field experiments			
		1983	1985	1986	1987
Growth Stages					
Vegetative Stage	-	+†	+	+	+
Reproductive Stage	-	+	+	+	+
Components of Growth Analysis					
Canopy Dry Weight	kg ha^{-1}	+	+	+	+
Leaf Dry Weight	kg ha^{-1}	+	+	+	+
Specific Leaf Area	cm^2 g^{-1}	+	+	+	+
Leaf Area Index	m^2 m^{-2}	+	+	+	+
Stem Dry Weight	kg ha^{-1}	+	+	+	+
Pod Dry Weight	kg ha^{-1}	+	+	+	+
Number of Pods	pods m^{-2}	+	+	+	+
Seed Dry Weight	kg ha^{-1}	+	+	+	+
Number of Seeds	seeds m^{-2}	na‡	na	+	+
Seed Size	mg	na	na	+	+
Shell Dry Weight	kg ha^{-1}	+	+	+	+
Percent Shelling	%	+	+	+	+
Pod Harvest Index	$g\ g^{-1}$	+	+	+	+
Percent Nitrogen	%	na	na	+	+
Disease Assessment					
Percent Necrosis	%	+	+	+	+
Percent Defoliation	%	+	+	+	+
Disease Severity	%	+	+	+	+

† Parameter was observed in the field.
‡ Parameter was not available to evaluate the models.

1986, and validated against field data obtained during 1983, 1985, and 1987. No input parameters were modified after the calibration process, except the distance (d) between the site of inoculum source and the peanut field under study. When the site of inoculum source was far from the peanut field under study, d was assumed to be 1000 m. In 1985 and 1987, peanut was planted in a field adjacent to sites where peanut was grown

during the previous year, and d was set at 10 m. During both calibration and validation, the fit of the predicted curves was compared graphically to the following observed variables: 1) leaf area index, 2) percent disease, 3) percent defoliation, and 4) disease severity.

Finally, simulations of peanut growth in 1986 were used for sensitivity analyses on parameters of the LATESPOT model. Each selected parameter, or set of parameters, were changed by ±10% and ±20% while holding all the other parameters constant at their calibrated or standard value. The relative sensitivity of each parameter was calculated with the following function:

$$\sigma_{(y/k)} = \{[y_{(k+\Delta k)} - y_{(k)}]/y_{(k)}\} \; / \; |\Delta k/k|$$

where y represents the disease severity at 105 DAP and k represents each parameter. The absolute value of the denominator was used to allow the determination of the direction of the change in the disease severity. The relative sensitivity can be interpreted as the relative change in y compared to the change in k. With a relative sensitivity of 0.5, a change of 10% in k will result in a change of 5% in y.

Results and Discussion

Calibration of PNUTGRO

One of the most important inputs to the LATESPOT model is the leaf area produced each day. The prediction of leaf area by PNUTGRO was not sufficiently accurate to allow testing of the prediction of the LATESPOT model. By estimating new genetic coefficients for each year of our evaluation, better predictions of PNUTGRO outputs were obtained under fungicide-treated conditions (Fig. 5-1, 5-2, 5-3, and 5-4). Genetic coefficients that were modified are given in Table 5-2. Many genetic

Table 5-2. Genetic coefficients that were modified to calibrate PNUTGRO when late leafspot was controlled with fungicides. The cultivar was Florunner for which coefficients were developed for crops grown in Gainesville (Boote *et al.*, 1989).

Genetic Coefficient	Definition†	Florunner Cultivar				
		Original Value	Calibration			
			1983	1985	1986	1987
		Phenology‡ and Development				
VARTHR(1)	PD§ to emergence	5.00	3.70	-¶	-	-
VARTHR(2)	PD§ to V1 stage	8.30	5.70	-	-	-
VARTHR(6)	PD§ from R1 to R2	8.00	5.00	14.00	14.00	-
LAGSD	PD§ from R2 to R5	11.00	9.00	-	-	-
VARTHR(10)	PD§ from R1 to R8	87.00	82.00	-	-	-
		Vegetative Growth				
SLAVAR	Specific leaf area	245.	220.	225.	238.	200.
PGLF	Normalized photo. rate	1.384	-	1.250	1.425	-
		Reproductive Growth				
PODVAR	Max. rate of pod addition	18.5	19.0	19.0	19.0	19.0
SHVAR	Max. growth rate per shell	19.0	-	-	18.0	-
SDVAR	Max. growth rate per seed	17.5	18.0	19.0	16.5	16.5
XFRT	Max. partitioning to fruit	0.85	0.90	-	0.75	-

† More detailed descriptions of the genetic coefficients are given in Boote *et al.* (1989).
‡ Growth stages V1, R1, R2, R5, and R8 are first leaf, beginning bloom, beginning peg, beginning seed, and harvest maturity, respectively (Boote, 1982).
§ Physiological days, which are equivalent to actual days if temperature is optimum for 24 hours per day.
¶ Original value of the coefficient was not modified.

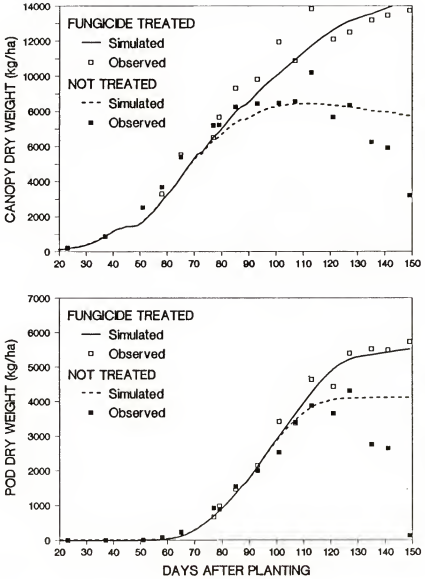
coefficients related to the phenology and the development of Florunner peanut were modified for the peanut crop of 1983. Only VARTHR(6), which is the number of physiological days from beginning flower to beginning peg (Boote *et al.*, 1989), was modified for the peanut crops of 1985 and 1986. In 1987, no modifications were necessary for the coefficients related to the phenology and the development. Genetic coefficients

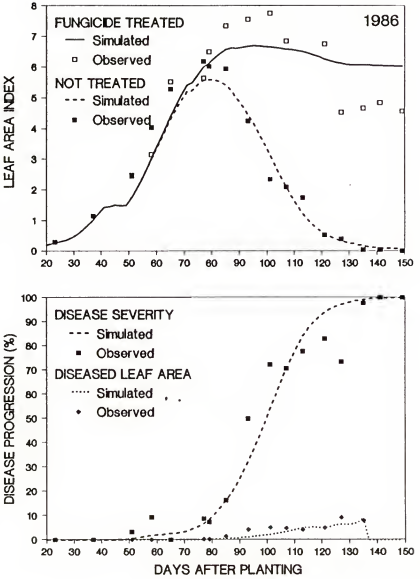
related to the vegetative growth of Florunner peanut were modified for the peanut crops of the four years. Reduction in SLAVAR, which is the specific leaf area ($cm^2\ g^{-1}$) of new growth during peak vegetative growth under optimum temperature (Boote *et al.*, 1989), was required in each of the four years. Minor changes in the genetic coefficients related to the reproductive growth of Florunner peanut were required for the four years also. A value of 19.0 was obtained for PODVAR, which is the maximum rate of pod addition under optimal environmental conditions (Boote *et al.*, 1989), in the four years.

Calibration of PNUTGRO-LATESPOT

Calibration of the PNUTGRO-LATESPOT model was achieved by changing sensitive parameters for which no quantitative values were available in the literature. Such parameters in LATESPOT were the expansion factor of the infected leaf area (f_E) and parameters related to the defoliation process (D_x, D_m, and D_h) (Table 5-3). Output variables considered in the calibration process of PNUTGRO-LATESPOT were the leaf area index (LAI), the disease severity, the percentage of defoliation, and the percentage of diseased leaf area. The disease severity is an expression of both defoliation and diseased leaf area (Plaut and Berger, 1980). These variables were obtained from plots where no fungicides were applied on the peanut crop to control late leafspot. Calibration was continued until all four model outputs were adequately predicted with the PNUTGRO-LATESPOT model (Fig. 5-1). The canopy dry weight and the pod dry weight were also predicted adequately by the model (Fig. 5-1). As discussed in the previous chapter, the LATESPOT model does not include functions to simulate pod losses. Simulated pod yields must be interpreted as potential yields, and can be verified by retrieving abscised pods from the soil (Chapter 2).

Figure 5-1. Calibration of the PNUTGRO-LATESPOT model with field data collected during summer 1986. Genetic coefficients of the PNUTGRO model were modified to predict the growth of peanut more accurately when fungicides were applied to control late leafspot (Table 5-2). Canopy dry weight, pod dry weight, and leaf area index are illustrated for both fungicide-treated and non-treated conditions. Disease severity, which includes defoliation, and percentage of diseased leaf area are illustrated only for non-treated conditions.


CANOPY DRY WEIGHT (kg/ha)
FUNGICIDE TREATED
Simulated
Observed
NOT TREATED
Simulated
Observed
POD DRY WEIGHT (kg/ha)
FUNGICIDE TREATED
Simulated
Observed
NOT TREATED
Simulated
Observed
DAYS AFTER PLANTING

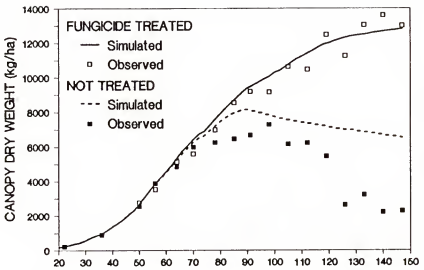

LEAF AREA INDEX
FUNGICIDE TREATED
1986
Simulated
Observed
NOT TREATED
Simulated
Observed
DISEASE PROGRESSION (%)
DISEASE SEVERITY
Simulated
Observed
DISEASED LEAF AREA
Simulated
Observed
DAYS AFTER PLANTING

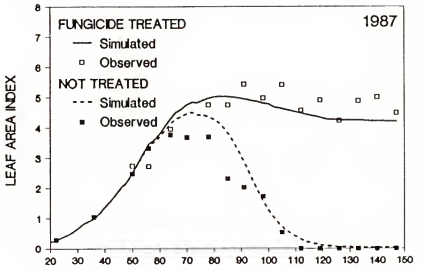
Validation of PNUTGRO-LATESPOT

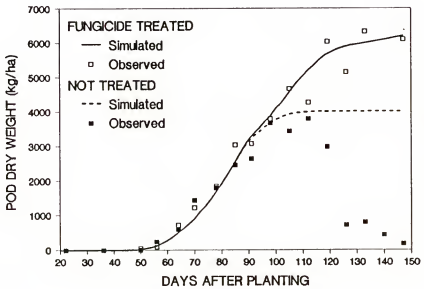
After calibration with the 1986 data only, the PNUTGRO-LATESPOT model adequately predicted the disease severity and the LAI of peanut crops planted on 2 June 1987 (Fig. 5-2), 15 May 1983 (Fig. 5-3), and 17 June 1985 (Fig. 5-4) when no fungicides were applied to control late leafspot. The percentage of diseased leaf area was predicted adequately in 1987, but was underestimated in 1983 and 1985. Pixley (1985) used a different technique to assess the percentage of diseased leaf area which may have led to this simulated underestimation of percentage of diseased leaf tissue in 1983 and 1985. In 1986 and 1987, necrotic leaf area was estimated by counting the number of lesions which were separated in the following classes: 1) lesion diameter of 1 mm and 2) lesion diameter of 4 mm, and by multiplying the number in each class by the corresponding circular area. In 1983 and 1985, necrotic leaf area was assessed with the aid of a modified Horsfall-Barratt standard area diagram.

For data of 1987, canopy dry weight and pod dry weight were predicted adequately by the PNUTGRO-LATESPOT model (Fig. 5-2). Differences observed after 120 DAP are due to pod losses which are not simulated by the model. For Pixley's data of 1983, canopy dry weight was predicted adequately by the PNUTGRO-LATESPOT model, but the pod dry weight was not (Fig. 5-3). The canopy dry weight is composed of the dry weights of the leaves, the stems, and the pods. The leaf dry weight was predicted adequately, but the stem dry weight was underestimated by the model. For some reason, reduction in stem dry weight was not observed in the peanut crop of 1983. A combination of an underestimated stem dry weight with an overestimated pod dry weight gave an adequate prediction of the canopy dry weight. For Pixley's data of 1985, canopy dry weight and pod dry weight were slightly

Figure 5-2. Validation of the PNUTGRO-LATESPOT model with field data collected during summer 1987. Genetic coefficients of the PNUTGRO model were modified to predict the growth of peanut more accurately when fungicides were applied to control late leafspot (Table 5-2). Canopy dry weight, pod dry weight, and leaf area index are illustrated for both fungicide-treated and non-treated conditions. Disease severity, which includes defoliation, and percentage of diseased leaf area are illustrated only for non-treated conditions.


FUNGICIDE TREATED
Simulated
Observed
NOT TREATED
Simulated
Observed
CANOPY DRY WEIGHT (kg/ha)
14000
12000
10000
8000
6000
4000
2000
0
20 30 40 50 60 70 80 90 100 110 120 130 140 150


FUNGICIDE TREATED
1987
Simulated
Observed
NOT TREATED
Simulated
Observed
LEAF AREA INDEX
8
7
6
5
4
3
2
1
0
20 30 40 50 60 70 80 90 100 110 120 130 140 150


FUNGICIDE TREATED
Simulated
Observed
NOT TREATED
Simulated
Observed
POD DRY WEIGHT (kg/ha)
7000
6000
5000
4000
3000
2000
1000
0
20 30 40 50 60 70 80 90 100 110 120 130 140 150
DAYS AFTER PLANTING

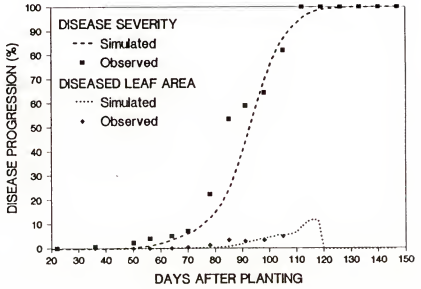
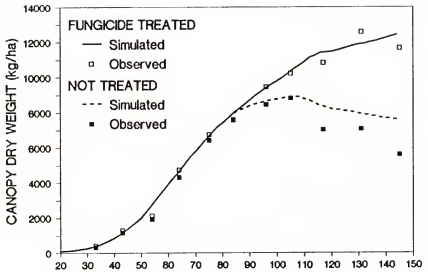
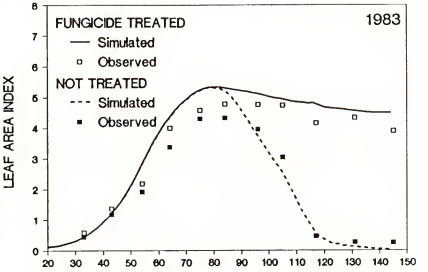
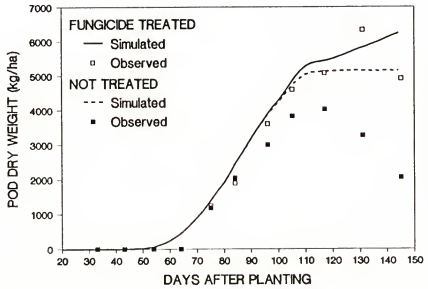

DISEASE SEVERITY
Simulated
Observed
DISEASED LEAF AREA
Simulated
Observed
DISEASE PROGRESSION (%)
100
90
80
70
60
50
40
30
20
10
0
20 30 40 50 60 70 80 90 100 110 120 130 140 150
DAYS AFTER PLANTING

Figure 5-3. Validation of the PNUTGRO-LATESPOT model with field data collected during summer 1983 by Pixley (1985). Genetic coefficients of the PNUTGRO model were modified to predict the growth of peanut more accurately when fungicides were applied to control late leafspot (Table 5-2). Canopy dry weight, pod dry weight, and leaf area index are illustrated for both fungicide-treated and non-treated conditions. Disease severity, which includes defoliation, and percentage of diseased leaf area are illustrated only for non-treated conditions.


FUNGICIDE TREATED
Simulated
Observed
NOT TREATED
Simulated
Observed
CANOPY DRY WEIGHT (kg/ha)
14000
12000
10000
8000
6000
4000
2000
0
20 30 40 50 60 70 80 90 100 110 120 130 140 150


FUNGICIDE TREATED
Simulated
Observed
NOT TREATED
Simulated
Observed
1983
LEAF AREA INDEX
8
7
6
5
4
3
2
1
0
20 30 40 50 60 70 80 90 100 110 120 130 140 150


FUNGICIDE TREATED
Simulated
Observed
NOT TREATED
Simulated
Observed
POD DRY WEIGHT (kg/ha)
7000
6000
5000
4000
3000
2000
1000
0
20 30 40 50 60 70 80 90 100 110 120 130 140 150
DAYS AFTER PLANTING

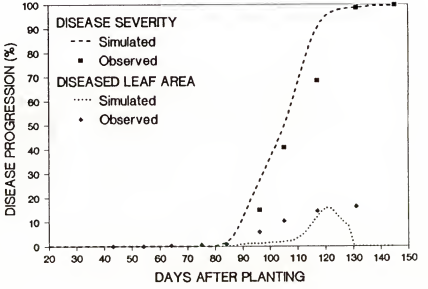
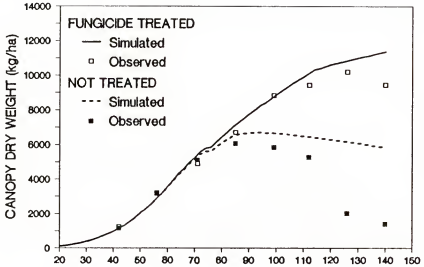
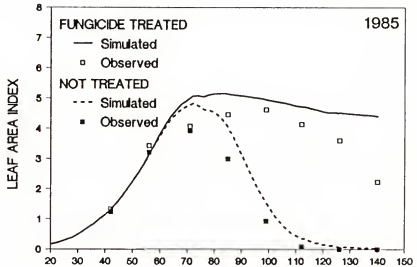
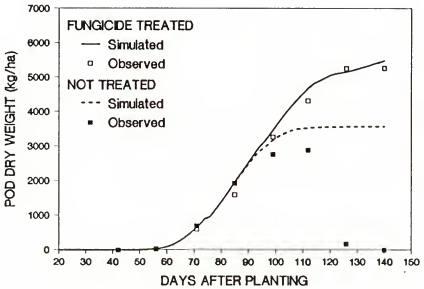
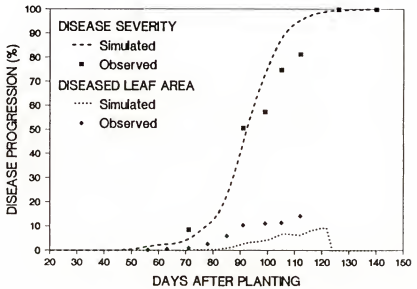

DISEASE SEVERITY
Simulated
Observed
DISEASED LEAF AREA
Simulated
Observed
DISEASE PROGRESSION (%)
100
90
80
70
60
50
40
30
20
10
0
20 30 40 50 60 70 80 90 100 110 120 130 140 150
DAYS AFTER PLANTING

Figure 5-4. Validation of the PNUTGRO-LATESPOT model with field data collected during summer 1985 by Pixley (unpublished). Genetic coefficients of the PNUTGRO model were modified to predict the growth of peanut more accurately when fungicides were applied to control late leafspot (Table 5-2). Canopy dry weight, pod dry weight, and leaf area index are illustrated for both fungicide-treated and non-treated conditions. Disease severity, which includes defoliation, and percentage of diseased leaf area are illustrated only for non-treated conditions.


FUNGICIDE TREATED
Simulated
Observed
NOT TREATED
Simulated
Observed
CANOPY DRY WEIGHT (kg/ha)
14000
12000
10000
8000
6000
4000
2000
0
20 30 40 50 60 70 80 90 100 110 120 130 140 150


FUNGICIDE TREATED
1985
Simulated
Observed
NOT TREATED
Simulated
Observed
LEAF AREA INDEX
8
7
6
5
4
3
2
1
0
20 30 40 50 60 70 80 90 100 110 120 130 140 150


FUNGICIDE TREATED
Simulated
Observed
NOT TREATED
Simulated
Observed
POD DRY WEIGHT (kg/ha)
7000
6000
5000
4000
3000
2000
1000
0
20 30 40 50 60 70 80 90 100 110 120 130 140 150
DAYS AFTER PLANTING


DISEASE SEVERITY
Simulated
Observed
DISEASED LEAF AREA
Simulated
Observed
DISEASE PROGRESSION (%)
100
90
80
70
60
50
40
30
20
10
0
20 30 40 50 60 70 80 90 100 110 120 130 140 150
DAYS AFTER PLANTING

overestimated by PNUTGRO-LATESPOT (Fig. 5-4). Differences observed after 120 DAP are due to pod losses which are not simulated by the model.

Sensitivity Analyses on LATESPOT Parameters

Sensitivity analyses are useful in many steps of the evaluation of a simulation model. They allow the study of the behavior of a simulated system by changing parameters and observing the effect on output variables. For the PNUTGRO-LATESPOT model, the disease severity at 105 DAP was selected as the output variable for the sensitivity analyses. Selected parameters were classified in five different biological processes that are involved in the relationships between late leafspot and the peanut crop: 1) dissemination of the conidia, 2) infection of peanut leaves, 3) pathogen development in the leaf, 4) spore release from infectious lesions, and 5) disease-induced defoliation (Table 5-3).

Almost all parameters related to the pathogen development in the leaf had relative sensitivities with absolute values over 0.50, which implies that they were the most sensitive parameters among those tested. Changes in the latent periods (ρ_1 and ρ_{50}) caused important changes in the disease severity. This result agrees with other reports about the importance of the latent period (ρ) as a component of resistance in the breeding of peanut lines that have partial resistance to late leafspot (Chiteka, 1987; Chiteka *et al.*, 1988; Watson, 1987). Changes in the expansion factor of infected leaf area (f_E) and the optimum temperature for pathogen development (T_o) also caused important changes in the disease severity. Changes in the parameter T_o caused larger changes in disease severity when it was reduced than when it was increased. The reduction of T_o caused the optimum temperature for pathogen development to shift below the range of average temperatures observed in Florida, and slowed pathogen development.

Table 5-3. Relative sensitivity of the PNUTGRO-LATESPOT model to changes in selected parameters. The growing season of 1986 was selected for the sensitivity analyses.

Parameter Tested‡	LATESPOT Parameter§	Value after Calib.	Relative Sensitivity: $\sigma_{(y/k)}$†			
			-20%	-10%	+10%	+20%
		Dissemination of Conidia				
X_s	DENLES	100	-0.016	-0.014	+0.014	+0.014
d_{max}	DISTMA	10000	-0.005	-0.003	+0.005	+0.004
		Infection				
e_i	CONEFF	0.85	-0.101	-0.095	+0.091	+0.088
n_{ls}	FACSIT	40000	+0.106	+0.098	-0.083	-0.082
s_r	FRSUSC	0.50	0.000	0.000	0.000	+0.001
c_g	FLN1	0.01	0.000	0.000	0.000	+0.001
		Pathogen Development in the Leaf				
i_c	ILAT	10	+0.132	+0.124	-0.098	-0.091
ρ_1	XLP1	19	-0.664	-0.555	+0.771	+0.520
ρ_{50}	XLP50	25	+1.182	+1.254	-1.323	-1.411
ρ_1 & ρ_{50}¶	-	-	+0.878	+0.849	-0.400	-0.593
T_o	COPTT	24	-4.074	-2.881	+0.686	+0.031
f_E	EXPFAC	1.10	-0.798	-0.664	+0.517	+0.451
		Spore Release				
c_p	CPDFAC	25000	-0.085	-0.078	+0.078	+0.072
i_1	IINF	2	-0.115#	-	-	+0.065#
i_{50}	ZINFEC	5	+0.086	+0.083	-0.069	-0.067
		Defoliation				
D_x	DFSMAX	0.75	-0.316	-0.246	+0.148	+0.107
D_m	DFSMIN	0.30	+0.065	+0.063	-0.065	-0.069
D_x & D_m¶	-	-	-0.278	-0.192	+0.060	+0.008
D_h	DEFHLT	0.68	+0.015	+0.055	-0.112	-0.148

† Equation defined in the text; Model output (y) was the disease severity at 105 DAP.
‡ These variables are defined in Table 4-1.
§ These variables are defined in Appendix E.
¶ Both variables were changed in the same direction at the same time.
# This variable was changed by ±50% because it is an integer variable.

Parameters related to the dissemination of the conidia, to the infection process, and to spore release from the infectious leaf area, had relative sensitivities with absolute values that were smaller than 0.15, which implies that they are the least sensitive parameters among those tested. Reduction in the number of conidia per unit of infectious leaf area (c_p) is considered as an important component of resistance (Watson, 1987) but in PNUTGRO-LATESPOT, a reduction of only 20% is not enough to create important changes. Watson (1987) obtained values of c_p of approximately 25000, 4000, and 2500 conidia cm^{-2} for Florunner, Southern Runner, and UF-81206 genotypes, respectively. Partial resistance to *C. personatum* in the latter two genotypes was associated with longer latent periods and reduced conidia production per unit of sporulating area.

Some parameters related to the defoliation process had intermediate absolute relative sensitivity (0.15 to 0.50). Presently, the defoliation process is mostly hypothetical because little information is available to allow a better understanding of the biological processes involved in the abscission of peanut leaflets infected by *C. personatum*.

Conclusion

The PNUTGRO-LATESPOT model adequately predicted the progression of the late leafspot disease for four different years, which represented a range of planting dates and locations in Florida. Prediction of the leaf area development is critical to predict the progression of late leafspot on peanut leaves. Adjustments were needed in the genetic file of PNUTGRO to obtain a simulated leaf area that approximated the observed leaf area when late leafspot was controlled with fungicides. Furthermore, neither PNUTGRO nor LATESPOT simulate peg deterioration which is believed to cause

pod abscission at the end of the growing season after complete defoliation by the disease. Peg deterioration normally causes important pod losses at harvest for leafspot-diseased peanut.

Presently, the LATESPOT model predicts the progression of late leafspot on Florunner peanut. The incorporation of peanut cultivars that have some level of resistance to late leafspot in the PNUTGRO-LATESPOT model would be possible with adequate information. Genetic coefficients need to be determined for a new peanut cultivar when late leafspot is controlled with fungicides. The latent period and the number of conidia produced per unit of infectious leaf area are probably the most important parameters to express the resistance to late leafspot. In some locations, early leafspot, induced by *C. arachidicola*, is the predominant disease. With adequate information, the calibration for the progression of the early leafspot disease would be possible. Again, the latent period and the number of conidia produced per unit of infectious leaf area are probably important characteristics in the differences between early leafspot and late leafspot. However, both diseases may be expected to react differently to various environmental conditions.

The PNUTGRO-LATESPOT model can be a very useful tool for education and research in plant epidemiology, crop production, and crop breeding for disease resistance. Presently, in the LATESPOT model the disease is considered as being present or absent. A fungicide application subroutine is needed to simulate the effect of protectant and systemic fungicides, and allow intermediate disease levels. The integration of PNUTGRO-LATESPOT into an expert-system program may aid specialists in crop production to make preventive and managerial decisions.

CHAPTER 6

CONCLUSION

Late leafspot, induced by *Cercosporidium personatum* (Berk. & Curt.) Deighton, was again shown to be destructive on a crop of peanut (*Arachis hypogaea* L.). Late leafspot first occurs on peanut leaflets as necrotic lesions and subsequently induces leaflet abscission. The photosynthetic rate of these leaflets was reduced by 4% for each percent increase in the fraction of necrotic leaf area. The infected leaf area, which is the leaf area occupied by the pathogen, is larger than the visible necrotic area and may explain this reduction in leaflet photosynthesis.

At the canopy level, reduction in leaflet photosynthesis caused by the presence of the pathogen, was found to be relatively unimportant for canopy photosynthesis when compared to the extensive disease-induced defoliation of the peanut crop. Disease severity, which is an expression of both defoliation and necrotic area on attached leaves, explained adequately the reduction of canopy photosynthesis due to the effect of late leafspot. Percent defoliation is by far the most important component of disease severity at the canopy level. The potential yield of peanut pods, which is defined as the sum of harvested pods and abscised pods retrieved from the soil, was reduced by approximately 40% in non-treated plots. This reduction was attributed to a reduction in canopy photosynthesis which caused less photosynthate to be available for pod growth.

Late leafspot is believed to be secondarily involved in pod losses which are more important close to harvest time when the peanut canopy is completely defoliated. Peg deterioration which is believed to cause pod abscission may be induced by saprophytic organisms near the soil surface and associated with defoliated leaves on the soil. Some of this peg deterioration occurs naturally in fungicide-treated plots at the end of the growing season and seems to be related to natural aging and is accelerated by high moisture and high soil temperature in the pegging zone.

A few mathematical models were used to describe disease progression in the peanut canopy. The use of standard epidemiological functions, such as the logistic, Gompertz, and Richards, did not provide enough information to understand the effect of the environment on disease progression from year to year. The concepts of healthy leaf area duration (HAD) and healthy area absorption (HAA) were used to predict pod yield. Acceptable results were obtained for peanut canopies that were treated with fungicides, but these concepts were invalidated for peanut canopies that were not treated with fungicides. Two reasons for this invalidation are proposed: 1) defoliation due to late leafspot is very different from artificial defoliation which was used to develop equations to predict pod yield from HAD and HAA, and 2) pod losses after complete defoliation of the peanut canopy need to be considered. The use of harvested pod yield in the computations of predicted pod yield from HAD and HAA was found to be inadequate because of pod losses. Potential pod yield should have been used because it is a better indicator of the cumulative photosynthetic capacity of a canopy.

Simulation models are an interesting alternative to study interactions between the environment, the plant, and the pathogen. In this research, a simulation model of the progression of late leafspot (LATESPOT) was developed and coupled to PNUTGRO, a simulation model of the growth and development of peanut, to help understand this pathosystem, to determine the effect of the pathogen on crop growth, and to predict yield reductions due to late leafspot. LATESPOT includes functions for dissemination of conidia, infection of leaf tissues by the conidia, disease development in the leaf which includes expansion, colonization and sporulation, and spore release from infectious lesions. All these processes are affected by daily environmental conditions. The effect of late leafspot on peanut was simulated adequately by reductions in leaf area index caused by disease-induced defoliation and by the presence to necrotic lesions. This last factor was negligible compared to the defoliation induced by late leafspot.

The prediction of PNUTGRO-LATESPOT was evaluated for four years, which represented a range of planting dates and locations in Florida. The disease severity and reductions in dry weight of vegetative and reproductive organs were predicted adequately by the PNUTGRO-LATESPOT model. However, PNUTGRO-LATESPOT predicts the potential pod yield and not the harvested pod yield because neither PNUTGRO nor LATESPOT simulate peg deterioration which is believed to cause loss in pod yield at the end of the growing season when the crop has been injured by the disease. In sensitivity analyses on selected parameters in the LATESPOT model, changes in parameters related to the pathogen development in the leaf were the most sensitive parameters. The latent period, the expansion factor of the infected leaf area, the incubation period, and the optimum temperature for

pathogen development in the leaf were among these sensitive parameters related to the pathogen development.

The PNUTGRO-LATESPOT model can be a very useful tool for education and research in plant epidemiology, crop production, and crop breeding for disease resistance. Presently, in the LATESPOT model the disease is considered as being present or absent. A fungicide application subroutine is needed to simulate the effect of protectant and systemic fungicides, with respect to timing and efficacy of fungicides used in the field. The integration of PNUTGRO-LATESPOT into an expert-system program may aid specialists in crop production to make preventive and managerial decisions.

APPENDIX A

FIELD OPERATIONS, WEATHER, AND GROWTH ANALYSIS

Table A-1. Field operations and growth staging during summer of 1986.

Mth	Day	Day of Year	Field Operation and Growth Staging
5	5	125	Mold Board Plowing
5	23	143	Harrowing with Triple-K
5	23	143	Herbicide Application - Benfluralin† (7.0 l ha^{-1})
5	23	143	Harrowing with Triple-K
5	29	149	Irrigation (19.00 mm)
6	2	153	Planting of Florunner Peanuts (20 seeds m^{-2})
6	3	154	Herbicide Application - Alachlor‡ (4.7 l ha^{-1})
6	9	160	Plant Emergence
6	25	176	Biomass Sampling no.1
6	29	180	Reproductive Stage R1§ - Beginning Bloom (GLC, NLC)¶
7	4	185	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
7	9	190	Biomass Sampling no.2
7	11	192	Reproductive Stage R2§ - Beginning Peg (GLC, NLC)¶
7	12	193	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
7	14	195	Gypsum†† Application (1009 kg ha^{-1})
7	21	202	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
7	22	203	Reproductive Stage R3§ - Beginning Pod (GLC, NLC)¶
7	23	204	Biomass Sampling no.3
7	30	211	Reproductive Stage R4§ - Full Pod (GLC, NLC)¶
7	30	211	Photosynthesis Measurement no.1
7	31	212	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
8	1	213	Reproductive Stage R5§ - Beginning Seed (GLC, NLC)¶
8	6	218	Biomass Sampling no.4
8	7	219	Insecticide Application - Methomyl‡‡ (2.3 l ha^{-1})
8	11	223	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
8	18	230	Photosynthesis Measurement no.2
8	20	232	Biomass Sampling no.5
8	21	233	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
8	21	233	Insecticide Application - Methomyl‡‡ (2.3 l ha^{-1})
8	23	235	Reproductive stage R6§ - Full seed (GLC, NLC)¶
8	26	238	Photosynthesis Measurement no.3

Table A-1 -- continued.

Mth	Day	Day of Year	Field Operation and Growth Staging
9	1	244	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
9	3	246	Reproductive Stage R7§ - Beginning Maturity (GLC, NLC)¶
9	3	246	Biomass Sampling no.6
9	4	247	Insecticide Application - Acephate§§ (1.1 kg ha^{-1})
9	11	254	Photosynthesis Measurement no.4
9	11	254	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
9	15	258	Insecticide Application - Acephate§§ (1.1 kg ha^{-1})
9	17	260	Biomass Sampling no.7
9	22	265	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
9	23	266	Photosynthesis Measurement no.5
10	1	274	Biomass Sampling no.8
10	2	275	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
10	6	279	Harvest no.1
10	7	280	Reproductive Stage R8§ - Harvest Maturity (NLC)¶
10	7	280	Photosynthesis Measurement no.6
10	15	288	Reproductive Stage R8§ - Harvest Maturity (GLC)¶
10	15	288	Reproductive Stage R9§ - Over-Mature Pod (NLC)¶
10	15	288	Biomass Sampling no.9
10	20	293	Harvest no.2
10	21	294	Photosynthesis Measurement no.7
10	29	302	Biomass Sampling no.10

† Benfluralin: selective pre-emergence herbicide (Balan^{R}): N-Butyl-N-ethyl-a,a,a-trifluoro-2,6-dinitro-p-toluidine.

‡ Alachlor: pre-plant incorporate, pre-emergence, and early post-emergence herbicide (Lasso^{R}): 2-Chloro-2'-6'-diethyl-N-(methoxymethyl)-acetanilide.

§ 50% of the plants in the sample demonstrate the desired trait of the given R stage (Boote, 1982)

¶ GLC: Good Leafspot Control (Fungicide-treated plots); NLC: No Leafspot Control (Non-treated plots)

Chlorothalonil: fungicide (Bravo^{R}): tetrachloroisophthalonitrile.

†† Gypsum: heavy clay soil conditioner, carrier, available source of elemental calcium and sulfur (calcium sulfate): $CaSO_4.2H_2O$.

‡‡ Methomyl: broad-spectrum insecticide (Lannate^{R}): S-Methyl-N-((methylcarbamoyl)oxy)thioacetimidate.

§§ Acephate: contact and systemic insecticide (Orthene^{R}): O,S-Dimethyl acetylphosphoramidothioate.

Table A-2. Field operations and growth staging during summer of 1987.

Mth	Day	Day of Year	Field Operation and Growth Staging
4	26	116	Mold Board Plowing
5	20	140	Disk Harrow
5	26	146	Herbicide Application - Benfluralin† (7.0 l ha^{-1})
5	26	146	Harrowing with Triple-K
6	1	152	Irrigation (12.70 mm)
6	2	153	Planting of Florunner Peanuts (20 seeds m^{-2})
6	3	154	Herbicide Application - Alachlor‡ (4.7 l ha^{-1})
6	4	155	Irrigation (11.43 mm)
6	9	160	Plant Emergence
6	9	160	Irrigation (12.70 mm)
6	16	167	Irrigation (12.70 mm)
6	24	175	Biomass Sampling no.1
6	25	176	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
7	1	182	Reproductive Stage R1§ - Beginning Bloom (GLC, NLC)¶
7	6	187	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
7	8	189	Reproductive Stage R2§ - Beginning Peg (GLC, NLC)¶
7	8	189	Biomass Sampling no.2
7	15	196	Reproductive Stage R3§ - Beginning Pod (GLC, NLC)¶
7	15	196	Gypsum†† Application (1345 kg ha^{-1})
7	17	198	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
7	22	203	Biomass Sampling no.3
7	25	206	Reproductive Stage R4§ - Full Pod (GLC, NLC)¶
7	28	209	Reproductive Stage R5§ - Beginning Seed (GLC, NLC)¶
7	28	209	Photosynthesis Measurement no.1
7	29	210	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
7	31	212	Insecticide Application - Acephate§§ (1.1 kg ha^{-1})
8	5	217	Biomass Sampling no.4
8	6	218	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
8	8	220	Reproductive Stage R6§ - Full Seed (GLC, NLC)¶
8	11	223	Photosynthesis Measurement no.2
8	14	226	Insecticide Application - Acephate§§ (1.1 kg ha^{-1})
8	16	228	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
8	19	231	Biomass Sampling no.5
8	24	236	Insecticide Application - Methomyl‡‡ (2.3 l ha^{-1})
8	26	238	Reproductive Stage R7§ - Beginning Maturity (GLC, NLC)¶
8	26	238	Photosynthesis Measurements no.3
8	27	239	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
8	28	240	Irrigation (17.78 mm)

Table A-2 -- continued.

Mth	Day	Day of Year	Field Operation and Growth Staging
9	1	244	Biomass Sampling no.6
9	1	244	Photosynthesis Measurement no.4
9	5	248	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
9	8	251	Photosynthesis Measurement no.5
9	9	252	Irrigation (31.75 mm)
9	15	258	Biomass Sampling no.7
9	16	259	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
9	22	265	Reproductive Stage R8§ - Harvest Maturity (NLC)¶
9	22	265	Photosynthesis Measurement no.6
9	24	267	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
9	29	272	Biomass Sampling no.8
9	30	273	Irrigation (10.16 mm)
10	2	275	Harvest no.1
10	6	279	Reproductive Stage R9§ - Over-Mature Pod (NLC)¶
10	6	279	Photosynthesis Measurement no.7
10	9	282	Fungicide Application - Chlorothalonil# (2.3 l ha^{-1})
10	13	286	Reproductive Stage R8§ - Harvest Maturity (GLC)¶
10	13	286	Biomass Sampling no.9
10	15	288	Irrigation (10.16 mm)
10	16	289	Harvest no.2
10	20	293	Photosynthesis Measurement no.8
10	27	300	Biomass Sampling no.10

† Benfluralin: selective pre-emergence herbicide (Balan^{R}): N-Butyl-N-ethyl-a,a,a-trifluoro-2,6-dinitro-p-toluidine.

‡ Alachlor: pre-plant incorporate, pre-emergence, and early post-emergence herbicide (Lasso^{R}): 2-Chloro-2′-6′-diethyl-N-(methoxymethyl)-acetanilide.

§ 50% of the plants in the sample demonstrate the desired trait of the given R stage (Boote, 1982)

¶ GLC: Good Leafspot Control (Fungicide-treated plots); NLC: No Leafspot Control (Non-treated plots)

Chlorothalonil: fungicide (Bravo^{R}): tetrachloroisophthalonitrile.

†† Gypsum: heavy clay soil conditioner, carrier, available source of elemental calcium and sulfur (calcium sulfate): $CaSO_4.2H_2O$.

‡‡ Methomyl: broad-spectrum insecticide (Lannate^{R}): S-Methyl-N-((methylcarbamoyl)oxy)thioacetimidate.

§§ Acephate: contact and systemic insecticide (Orthene^{R}): O,S-Dimethyl acetylphosphoramidothioate.

Table A-3. Weather data during summer of 1986 at Gainesville, Florida.

Mth	Day	Day of Year	Solar Radiation	Maximum Temp.	Minimum Temp.	Minimum Relative Humidity	Rain	Irrig.
			MJ m^{-2}	°C		%	mm	
6	1	152	25.80	35.0	20.0	42	4.8	0.0
6	2	153	19.00	35.0	21.1	50	10.2	0.0
6	3	154	23.00	34.4	20.0	40	0.0	0.0
6	4	155	20.60	34.4	20.0	48	0.0	0.0
6	5	156	21.00	32.8	21.1	45	0.3	0.0
6	6	157	23.00	34.4	19.4	40	0.0	0.0
6	7	158	25.00	35.0	21.7	40	0.3	0.0
6	8	159	29.80	34.4	20.6	38	0.0	0.0
6	9	160	20.10	35.0	22.2	40	0.0	0.0
6	10	161	19.10	35.0	22.8	30	24.1	0.0
6	11	162	16.40	31.7	21.1	50	1.5	0.0
6	12	163	19.50	32.8	23.3	42	0.0	0.0
6	13	164	19.70	32.2	21.7	66	9.1	0.0
6	14	165	13.50	31.1	18.3	75	44.2	0.0
6	15	166	17.80	30.6	20.6	70	7.6	0.0
6	16	167	22.20	32.2	20.0	64	0.5	0.0
6	17	168	22.70	32.8	21.1	59	0.0	0.0
6	18	169	17.20	33.3	20.6	62	10.4	0.0
6	19	170	10.20	30.0	20.6	62	23.1	0.0
6	20	171	11.40	27.8	21.7	61	2.8	0.0
6	21	172	22.40	32.8	21.7	52	0.5	0.0
6	22	173	23.90	32.8	21.1	55	0.0	0.0
6	23	174	26.50	33.3	21.1	51	0.0	0.0
6	24	175	28.70	33.3	20.0	70	0.0	0.0
6	25	176	23.60	33.3	21.1	54	0.0	0.0
6	26	177	28.70	35.0	21.1	45	0.0	0.0
6	27	178	24.20	35.0	21.1	48	0.0	0.0
6	28	179	24.50	35.0	21.7	44	0.0	0.0
6	29	180	25.80	35.0	20.0	50	0.0	0.0
6	30	181	23.10	32.2	20.6	60	4.1	0.0
7	1	182	15.90	32.2	22.2	77	5.1	0.0
7	2	183	24.30	33.3	21.7	50	0.0	0.0
7	3	184	18.10	32.2	22.8	64	9.9	0.0
7	4	185	24.90	33.9	21.1	50	0.0	0.0
7	5	186	13.80	33.9	20.6	65	8.4	0.0
7	6	187	27.00	33.3	20.0	50	0.3	0.0
7	7	188	25.20	33.9	20.0	54	35.6	0.0
7	8	189	25.20	34.4	21.7	50	0.0	0.0
7	9	190	26.00	34.4	21.7	46	0.0	0.0
7	10	191	26.50	35.6	21.7	53	0.0	0.0
7	11	192	13.70	34.4	22.2	67	0.8	0.0
7	12	193	23.60	34.4	21.7	52	0.0	0.0
7	13	194	25.10	35.0	21.1	58	0.8	0.0
7	14	195	27.70	35.0	21.1	42	0.0	0.0
7	15	196	27.00	35.6	21.1	45	0.0	0.0

Table A-3 -- continued.

Mth	Day	Day of Year	Solar Radiation	Maximum Temp.	Minimum Temp.	Minimum Relative Humidity	Rain	Irrig.
			MJ m^{-2}	°C		%	mm	
7	16	197	18.50	34.4	22.2	52	0.0	0.0
7	17	198	22.70	35.6	22.2	54	0.0	0.0
7	18	199	24.00	35.6	22.2	45	0.0	0.0
7	19	200	25.60	36.7	22.8	52	0.0	0.0
7	20	201	23.70	37.2	23.9	61	0.0	0.0
7	21	202	19.30	36.7	22.8	58	5.6	0.0
7	22	203	8.50	36.7	21.1	75	52.1	0.0
7	23	204	15.50	32.2	21.7	62	3.3	0.0
7	24	205	23.90	32.8	21.7	58	15.7	0.0
7	25	206	21.10	32.8	22.2	60	0.0	0.0
7	26	207	19.90	32.2	22.8	65	2.8	0.0
7	27	208	10.50	28.3	21.7	79	24.6	0.0
7	28	209	15.30	30.0	21.7	80	6.3	0.0
7	29	210	22.10	32.8	22.2	62	0.0	0.0
7	30	211	21.70	33.9	22.8	70	0.0	0.0
7	31	212	22.50	36.1	23.9	64	0.0	0.0
8	1	213	22.10	37.2	22.2	44	0.0	0.0
8	2	214	9.80	36.7	21.7	70	2.5	0.0
8	3	215	13.30	31.1	20.6	75	9.9	0.0
8	4	216	10.20	31.7	21.7	68	4.3	0.0
8	5	217	16.50	32.8	20.6	56	3.0	0.0
8	6	218	23.70	33.9	21.1	46	0.5	0.0
8	7	219	22.80	34.4	20.6	53	20.6	0.0
8	8	220	20.90	36.1	21.7	58	0.0	0.0
8	9	221	19.10	34.4	21.7	50	0.0	0.0
8	10	222	23.80	35.0	20.6	45	0.0	0.0
8	11	223	18.50	34.4	20.6	53	13.5	0.0
8	12	224	14.60	32.2	21.7	55	17.5	0.0
8	13	225	8.30	28.3	21.7	73	10.9	0.0
8	14	226	5.30	28.9	21.7	80	26.9	0.0
8	15	227	19.00	30.6	21.1	70	2.5	0.0
8	16	228	23.70	31.7	21.7	62	0.0	0.0
8	17	229	18.30	33.9	22.2	57	0.5	0.0
8	18	230	20.10	33.3	21.1	46	0.0	0.0
8	19	231	17.40	33.3	21.7	53	0.8	0.0
8	20	232	9.10	30.6	23.3	66	51.1	0.0
8	21	233	15.50	31.7	20.6	61	13.5	0.0
8	22	234	22.20	31.1	20.6	55	4.1	0.0
8	23	235	26.30	35.0	21.7	52	0.0	0.0
8	24	236	26.60	34.4	21.7	92	5.1	0.0
8	25	237	20.90	34.4	22.2	58	1.5	0.0
8	26	238	26.00	34.4	22.8	54	0.0	0.0
8	27	239	21.30	33.9	22.2	62	1.0	0.0
8	28	240	11.60	29.4	22.2	83	2.3	0.0
8	29	241	3.80	25.0	21.7	80	21.3	0.0

Table A-3 -- continued.

Mth	Day	Day of Year	Solar Radiation	Maximum Temp.	Minimum Temp.	Minimum Relative Humidity	Rain	Irrig.
			MJ m^{-2}	°C		%	mm	
8	30	242	14.40	31.1	21.1	70	0.0	0.0
8	31	243	13.10	30.0	21.1	80	3.6	0.0
9	1	244	20.10	32.8	21.7	63	0.5	0.0
9	2	245	19.60	32.8	20.6	58	0.0	0.0
9	3	246	20.30	32.8	21.7	60	0.8	0.0
9	4	247	19.40	33.3	21.7	60	0.0	0.0
9	5	248	19.50	32.2	21.7	58	29.7	0.0
9	6	249	16.60	32.8	22.2	60	0.8	0.0
9	7	250	17.20	32.8	21.7	59	0.0	0.0
9	8	251	15.50	31.7	21.7	65	0.0	0.0
9	9	252	13.70	31.7	20.6	67	21.1	0.0
9	10	253	13.60	30.6	20.6	63	8.6	0.0
9	11	254	19.50	32.8	19.4	55	4.6	0.0
9	12	255	16.10	32.8	20.6	58	0.0	0.0
9	13	256	17.60	32.8	21.7	66	5.6	0.0
9	14	257	17.60	32.8	25.0	60	0.0	0.0
9	15	258	20.30	32.8	21.7	57	0.0	0.0
9	16	259	18.30	32.8	20.0	.	0.0	0.0
9	17	260	18.10	32.8	21.1	.	0.0	0.0
9	18	261	13.50	30.0	20.0	59	2.8	0.0
9	19	262	21.50	31.1	20.6	50	0.0	0.0
9	20	263	21.40	32.8	19.4	49	0.0	0.0
9	21	264	18.80	32.2	18.3	50	0.0	0.0
9	22	265	19.00	32.8	19.4	50	0.0	0.0
9	23	266	20.70	32.2	20.0	44	0.0	0.0
9	24	267	15.30	33.3	20.0	45	0.0	0.0
9	25	268	19.50	34.4	20.6	48	0.0	0.0
9	26	269	19.50	33.3	20.6	51	0.0	0.0
9	27	270	15.50	33.3	22.2	58	0.0	0.0
9	28	271	11.80	33.3	21.1	56	4.3	0.0
9	29	272	15.70	33.3	20.0	49	0.0	0.0
9	30	273	19.60	33.3	21.1	45	0.0	0.0
10	1	274	16.70	33.9	21.1	44	0.0	0.0
10	2	275	18.20	35.0	20.6	40	0.0	0.0
10	3	276	18.30	33.3	20.0	50	0.0	0.0
10	4	277	16.40	33.3	18.9	46	0.0	0.0
10	5	278	16.50	33.9	18.9	46	0.0	0.0
10	6	279	16.50	33.9	21.7	49	0.0	0.0
10	7	280	16.40	33.3	21.1	45	10.4	0.0
10	8	281	13.20	32.2	21.1	46	5.6	0.0
10	9	282	13.80	32.2	19.4	42	16.0	0.0
10	10	283	7.60	31.7	19.4	.	36.3	0.0
10	11	284	16.20	30.6	20.0	59	0.0	0.0
10	12	285	12.60	30.6	20.6	66	0.0	0.0

Table A-3 -- continued.

Mth	Day	Day of Year	Solar Radiation	Maximum Temp.	Minimum Temp.	Minimum Relative Humidity	Rain	Irrig.
			MJ m^{-2}	°C		%	mm	
10	13	286	12.70	32.2	21.7	58	0.0	0.0
10	14	287	14.60	32.8	21.1	46	0.0	0.0
10	15	288	3.80	30.0	16.7	48	0.0	0.0
10	16	289	19.20	23.9	11.1	42	0.0	0.0
10	17	290	18.00	25.0	11.1	43	0.0	0.0
10	18	291	15.90	25.6	13.3	47	0.0	0.0
10	19	292	15.90	23.9	11.7	62	0.0	0.0
10	20	293	15.90	25.0	10.0	50	0.0	0.0
10	21	294	18.50	25.6	9.4	40	0.0	0.0
10	22	295	14.90	27.2	10.6	34	0.0	0.0
10	23	296	15.00	29.4	13.3	43	0.0	0.0
10	24	297	15.10	30.0	15.6	46	0.0	0.0
10	25	298	3.50	29.4	20.0	94	2.5	0.0
10	26	299	5.60	25.6	20.0	94	1.0	0.0
10	27	300	11.90	26.1	16.7	59	13.2	0.0
10	28	301	11.50	25.6	13.3	47	0.0	0.0
10	29	302	2.70	21.1	17.2	90	6.1	0.0
10	30	303	3.50	21.7	16.1	95	7.6	0.0
10	31	304	6.80	26.1	19.4	86	0.0	0.0

Table A-4. Weather data during summer of 1987 at Gainesville, Florida.

Mth	Day	Day of Year	Solar Radiation	Maximum Temp.	Minimum Temp.	Minimum Relative Humidity	Rain	Irrig.
			MJ m^{-2}	°C		%	mm	
6	1	152	27.00	33.3	20.0	33	0.0	12.7
6	2	153	24.90	35.0	21.1	34	0.0	0.0
6	3	154	25.40	33.9	21.7	43	0.0	0.0
6	4	155	12.30	31.7	22.2	64	0.0	11.4
6	5	156	16.50	31.7	20.6	60	0.0	0.0
6	6	157	22.50	31.7	20.6	49	2.3	0.0
6	7	158	26.70	31.7	19.4	43	0.0	0.0
6	8	159	25.70	32.2	17.2	37	0.0	0.0
6	9	160	28.30	33.3	16.1	32	0.0	12.7
6	10	161	25.40	34.4	20.6	36	0.0	0.0
6	11	162	22.80	34.4	20.6	63	0.0	0.0
6	12	163	20.70	33.3	23.3	65	0.0	0.0
6	13	164	17.80	33.3	21.7	65	0.0	0.0
6	14	165	13.70	30.0	21.1	68	4.8	0.0
6	15	166	26.20	33.9	20.6	60	0.0	0.0
6	16	167	25.70	35.0	20.0	73	0.0	12.7
6	17	168	22.40	32.2	21.1	69	0.0	0.0
6	18	169	17.80	32.8	21.1	76	0.0	0.0
6	19	170	23.30	32.8	21.1	66	0.0	0.0
6	20	171	19.30	35.0	22.2	73	0.0	0.0
6	21	172	16.10	33.3	22.2	80	0.0	0.0
6	22	173	16.50	33.3	22.8	88	13.7	0.0
6	23	174	16.50	33.3	23.3	92	6.6	0.0
6	24	175	23.90	33.9	21.1	59	0.5	0.0
6	25	176	20.40	33.9	20.6	66	0.0	0.0
6	26	177	17.00	33.3	23.3	79	6.3	0.0
6	27	178	15.60	30.0	22.2	96	35.1	0.0
6	28	179	17.70	32.2	22.8	68	1.0	0.0
6	29	180	13.30	31.7	21.1	65	4.6	0.0
6	30	181	21.40	32.8	21.7	18	0.0	0.0
7	1	182	23.10	34.4	23.3	73	0.0	0.0
7	2	183	19.30	33.9	23.3	74	5.1	0.0
7	3	184	21.00	32.8	22.8	92	1.3	0.0
7	4	185	22.20	35.0	22.2	50	0.0	0.0
7	5	186	17.20	35.0	21.7	86	0.0	0.0
7	6	187	26.40	35.6	22.2	44	0.0	0.0
7	7	188	24.60	34.4	22.2	.	0.8	0.0
7	8	189	21.60	34.4	21.7	54	0.5	0.0
7	9	190	19.40	36.7	21.1	53	25.9	0.0
7	10	191	19.20	35.0	21.7	56	11.9	0.0
7	11	192	22.00	35.0	22.8	52	0.0	0.0
7	12	193	21.70	35.6	23.3	60	0.0	0.0
7	13	194	25.10	36.7	24.4	44	0.0	0.0
7	14	195	9.20	31.1	22.2	66	3.8	0.0
7	15	196	8.40	28.9	23.3	.	3.8	0.0

Table A-4 -- continued.

Mth	Day	Day of Year	Solar Radiation	Maximum Temp.	Minimum Temp.	Minimum Relative Humidity	Rain	Irrig.
			MJ m^{-2}	°C		%	mm	
7	16	197	24.30	33.3	22.8	50	0.0	0.0
7	17	198	25.70	32.8	20.0	44	0.0	0.0
7	18	199	18.60	32.8	23.3	85	0.8	0.0
7	19	200	20.20	32.2	21.1	96	1.8	0.0
7	20	201	19.00	32.8	22.8	.	0.5	0.0
7	21	202	19.00	33.3	24.4	88	20.1	0.0
7	22	203	26.20	33.9	21.1	50	0.0	0.0
7	23	204	24.40	35.6	20.0	49	0.0	0.0
7	24	205	23.80	35.0	20.0	60	14.5	0.0
7	25	206	17.00	32.8	22.2	98	1.0	0.0
7	26	207	22.00	33.9	21.7	70	1.0	0.0
7	27	208	20.30	33.9	21.7	58	0.0	0.0
7	28	209	24.60	33.3	22.2	52	5.1	0.0
7	29	210	22.80	33.3	22.8	54	0.0	0.0
7	30	211	18.70	33.3	23.3	58	0.0	0.0
7	31	212	11.60	31.1	22.2	70	1.3	0.0
8	1	213	21.20	33.3	21.1	59	2.5	0.0
8	2	214	17.30	31.7	22.8	70	18.0	0.0
8	3	215	14.50	31.7	22.2	70	1.8	0.0
8	4	216	22.30	32.2	22.8	63	10.4	0.0
8	5	217	16.30	32.2	23.9	63	1.3	0.0
8	6	218	23.50	34.4	23.3	54	0.0	0.0
8	7	219	24.40	35.6	24.4	52	0.0	0.0
8	8	220	23.70	37.8	23.9	80	0.0	0.0
8	9	221	22.80	36.7	24.4	64	0.0	0.0
8	10	222	18.80	35.6	24.4	56	88.9	0.0
8	11	223	15.60	35.0	20.6	57	5.6	0.0
8	12	224	15.00	32.8	21.7	66	3.3	0.0
8	13	225	12.90	30.0	22.8	75	0.0	0.0
8	14	226	7.60	27.8	22.8	83	2.5	0.0
8	15	227	7.30	27.8	22.2	88	2.0	0.0
8	16	228	16.80	31.7	21.7	73	0.0	0.0
8	17	229	22.00	33.9	22.8	62	0.0	0.0
8	18	230	21.40	34.4	22.8	56	0.0	0.0
8	19	231	19.30	33.9	22.2	58	0.0	0.0
8	20	232	23.50	34.4	23.3	55	0.0	0.0
8	21	233	21.00	35.0	22.8	52	0.0	0.0
8	22	234	22.50	33.9	22.8	42	0.0	0.0
8	23	235	22.50	35.0	21.7	42	0.0	0.0
8	24	236	22.40	36.7	20.0	44	0.0	0.0
8	25	237	21.40	35.0	22.2	44	0.0	0.0
8	26	238	22.50	35.6	22.2	46	0.0	0.0
8	27	239	22.10	36.1	22.2	46	0.0	0.0
8	28	240	22.10	35.6	22.8	48	0.0	17.8
8	29	241	21.70	36.1	22.8	47	0.0	0.0

Table A-4 -- continued.

Mth	Day	Day of Year	Solar Radiation	Maximum Temp.	Minimum Temp.	Minimum Relative Humidity	Rain	Irrig.
			MJ m^{-2}	°C		%	mm	
8	30	242	15.30	35.0	23.3	60	0.8	0.0
8	31	243	21.40	34.4	22.2	56	0.0	0.0
9	1	244	14.40	33.9	22.2	52	0.3	0.0
9	2	245	7.60	27.8	20.6	72	2.0	0.0
9	3	246	7.70	28.9	22.8	.	1.3	0.0
9	4	247	12.50	31.1	22.2	.	0.0	0.0
9	5	248	14.30	33.3	21.7	.	0.0	0.0
9	6	249	11.20	32.2	22.2	.	2.0	0.0
9	7	250	21.60	34.4	20.6	.	0.0	0.0
9	8	251	18.20	32.8	20.6	53	1.0	0.0
9	9	252	21.40	34.4	21.7	40	0.0	31.8
9	10	253	18.80	35.0	21.7	46	0.0	0.0
9	11	254	11.50	32.8	22.2	55	0.5	0.0
9	12	255	7.80	31.7	22.2	75	46.7	0.0
9	13	256	17.60	32.2	21.7	58	3.3	0.0
9	14	257	20.00	33.9	21.7	.	0.0	0.0
9	15	258	20.30	33.9	22.2	.	0.0	0.0
9	16	259	20.70	34.4	22.2	.	0.0	0.0
9	17	260	20.70	34.4	22.2	.	0.0	0.0
9	18	261	16.50	32.8	20.6	.	0.5	0.0
9	19	262	14.10	31.7	21.7	.	31.5	0.0
9	20	263	13.20	31.7	22.2	.	0.0	0.0
9	21	264	20.30	31.7	20.0	45	0.0	0.0
9	22	265	10.40	30.6	18.3	47	0.0	0.0
9	23	266	7.60	25.6	21.7	55	0.0	0.0
9	24	267	20.80	30.0	15.6	35	0.0	0.0
9	25	268	19.30	30.6	15.0	34	0.0	0.0
9	26	269	15.80	31.1	16.7	42	0.0	0.0
9	27	270	15.80	32.8	17.8	38	0.0	0.0
9	28	271	14.50	32.2	20.6	37	0.0	0.0
9	29	272	15.30	33.3	21.1	38	0.8	0.0
9	30	273	6.50	30.0	22.2	52	3.3	10.2
10	1	274	21.90	27.8	16.1	28	6.9	0.0
10	2	275	22.50	28.9	14.4	38	0.0	0.0
10	3	276	22.30	28.9	12.8	26	0.0	0.0
10	4	277	22.30	28.9	10.0	58	0.0	0.0
10	5	278	21.80	28.3	11.1	36	0.0	0.0
10	6	279	20.70	27.8	11.7	37	0.0	0.0
10	7	280	19.10	26.7	12.8	19	0.0	0.0
10	8	281	19.90	26.1	7.8	23	0.0	0.0
10	9	282	17.70	27.8	10.6	46	0.0	0.0
10	10	283	11.30	27.8	16.7	48	0.0	0.0
10	11	284	4.10	24.4	20.6	.	0.0	0.0
10	12	285	6.90	25.0	19.4	44	0.0	0.0

Table A-4 -- continued.

Mth	Day	Day of Year	Solar Radiation	Maximum Temp.	Minimum Temp.	Minimum Relative Humidity	Rain	Irrig.
			MJ m^{-2}	°C		%	mm	
10	13	286	19.00	21.7	13.3	43	0.0	0.0
10	14	287	20.10	22.2	10.0	43	0.0	0.0
10	15	288	13.40	24.4	9.4	59	0.0	10.2
10	16	289	20.00	27.8	11.7	35	0.0	0.0
10	17	290	17.70	29.4	15.0	45	0.0	0.0
10	18	291	19.90	29.4	15.0	27	0.0	0.0
10	19	292	16.70	31.1	15.6	49	0.0	0.0
10	20	293	16.60	31.1	16.7	41	0.0	0.0
10	21	294	17.30	28.9	16.1	34	0.0	0.0
10	22	295	16.60	22.8	6.7	36	0.0	0.0
10	23	296	13.90	24.4	10.0	50	0.0	0.0
10	24	297	13.70	27.8	14.4	46	0.0	0.0
10	25	298	7.60	22.2	17.8	57	0.0	0.0
10	26	299	10.70	26.1	14.4	65	0.0	0.0
10	27	300	9.60	31.7	16.7	51	0.0	0.0
10	28	301	18.00	21.1	13.3	23	0.0	0.0
10	29	302	16.90	22.2	4.4	21	0.0	0.0
10	30	303	17.40	25.6	7.2	23	0.0	0.0
10	31	304	7.90	23.9	13.9	66	0.0	0.0

Table A-5. Growth analysis data and disease assessment for summer of 1986.

Mth	Day	DAP	Sam†	Growth Stage Veg.	Growth Stage Rep.	Dry Weight Biomass	Dry Weight Stem	Dry Weight Leaf	Specific Leaf Area	Leaf Area Index
						g m^{-2}			cm^2 g^{-1}	m^2 m^{-2}
					Fungicide Treated					
6	25	23	B	7.3	0	22.2	8.5	13.6	214.6	0.29
7	9	37	B	10.5	1	88.8	39.7	49.1	231.3	1.14
7	23	51	B	14.7	3	250.8	133.1	116.3	213.0	2.48
7	30	58	P	15.5	4	330.6	171.3	152.5	208.7	3.15
8	6	65	B	17.1	5	554.5	304.9	224.8	246.3	5.52
8	18	77	P	21.0	5	652.8	341.0	243.9	230.7	5.63
8	20	79	B	21.7	5	768.3	405.2	264.0	246.4	6.50
8	26	85	P	23.3	6	932.2	469.6	315.2	231.6	7.33
9	3	93	B	25.0	7	981.2	457.2	307.7	245.6	7.55
9	11	101	P	26.5	7	1195.8	507.3	345.6	224.7	7.75
9	17	107	B	28.7	7	1089.6	454.8	296.6	231.4	6.85
9	23	113	P	27.0	7	1384.9	556.8	364.0	220.6	8.05
10	1	121	B	29.0	7	1210.7	476.4	290.3	231.6	6.74
10	7	127	P	28.0	7	1251.2	507.6	203.0	222.9	4.53
10	15	135	B	29.7	8	1318.9	543.8	222.3	210.5	4.66
10	21	141	P	31.5	8	1347.7	533.0	264.3	183.3	4.85
10	29	149	B	30.5	8	1374.7	566.7	234.1	195.8	4.57
					Not Treated					
6	25	23	B	7.6	0	22.2	8.5	13.6	214.6	0.29
7	9	37	B	10.7	1	88.8	39.7	49.1	231.3	1.14
7	23	51	B	14.3	2	253.7	136.5	116.5	210.8	2.45
7	30	58	P	15.5	4	369.2	194.0	166.2	243.3	4.03
8	6	65	B	16.7	5	542.1	293.3	225.2	235.1	5.28
8	18	77	P	21.6	5	721.7	376.7	251.3	245.0	6.17
8	20	79	B	21.7	5	722.9	383.1	250.2	240.6	6.02
8	26	85	P	23.6	6	826.8	410.6	260.7	228.0	5.94
9	3	93	B	25.5	7	843.8	461.5	180.7	235.3	4.24
9	11	101	P	26.0	7	848.5	487.2	107.6	218.3	2.33
9	17	107	B	28.0	7	856.8	416.1	99.4	211.2	2.10
9	23	113	P	29.5	7	1022.4	544.8	88.5	197.2	1.74
10	1	121	B	31.2	7	766.3	373.1	27.0	190.3	0.51
10	7	127	P	32.0	8	835.4	380.4	23.3	173.4	0.40
10	15	135	B	30.5	9	625.8	347.2	1.9	187.8	0.03
10	21	141	P	29.0	9	592.5	324.0	3.6	94.1	0.03
10	29	149	B	.	9	322.3	308.6	0.0	.	0.00

† Sampling method: B = Biomass (1 m of row, 2 treatments, 4 blocks); P = Photosynthesis (0.61 m of row, 2 treatments, 2 blocks).

Table A-5 -- continued.

Mth	Day	DAP	Sam†	Percent Light		Pod Number			Seed Number	Seeds per Pod
				Interc.	Absorp.	Immat.‡	Mature	Total		
				%		m^{-2}				
				Fungicide Treated						
6	25	23	B	11.1	7.6§	0	0	0	0	.
7	9	37	B	35.0	31.5§	0	0	0	0	.
7	23	51	B	77.8	73.5	19	0	19	0	.
7	30	58	P	88.1	85.1	32	0	32	0	.
8	6	65	B	96.5	93.2	193	32	225	67	2.08
8	18	77	P	99.2	95.5	170	102	273	197	1.92
8	20	79	B	99.2	95.5	275	185	461	331	1.79
8	26	85	P	99.1	95.6	261	207	468	400	1.94
9	3	93	B	99.3	96.1	347	282	630	519	1.84
9	11	101	P	.	.	417	379	797	684	1.80
9	17	107	B	99.3	96.1	169	413	583	724	1.75
9	23	113	P	98.9	95.6	205	654	859	868	1.33
10	1	121	B	98.2	94.7	228	465	694	760	1.63
10	7	127	P	.	.	120	482	602	833	1.73
10	15	135	B	98.8	94.7	274	518	793	869	1.68
10	21	141	P	96.9	92.5	152	487	640	808	1.66
10	29	149	B	97.5	92.5	92	511	604	881	1.72
				Not Treated						
6	25	23	B	11.1	7.6§	0	0	0	0	.
7	9	37	B	35.0	31.5§	0	0	0	0	.
7	23	51	B	76.5	72.3	12	0	12	0	.
7	30	58	P	79.0	75.7	247	0	247	0	.
8	6	65	B	96.1	92.9	204	19	223	37	1.89
8	18	77	P	98.8	94.7	232	145	378	281	1.93
8	20	79	B	98.8	94.7	190	174	365	293	1.68
8	26	85	P	99.2	95.7	317	232	549	431	1.86
9	3	93	B	97.0	94.1	290	261	552	487	1.86
9	11	101	P	.	.	347	280	627	523	1.87
9	17	107	B	89.0	85.6	205	359	564	646	1.80
9	23	113	P	76.5	72.7	393	393	786	705	1.79
10	1	121	B	58.2	53.7	122	331	453	588	1.77
10	7	127	P	.	.	258	447	705	741	1.66
10	15	135	B	45.5	40.0	145	249	394	441	1.77
10	21	141	P	45.6	39.5	92	248	341	404	1.63
10	29	149	B	44.3	38.8	5	11	17	22	1.99

† Sampling method: B = Biomass (1 m of row, 2 treatments, 4 blocks); P = Photosynthesis (0.61 m of row, 2 treatments, 2 blocks).

‡ Immature pods: pods that shrunk after drying.

§ Light absorption was corrected for the reflection from the soil. A 3.5% reflection from the canopy was assumed.

Table A-5 -- continued.

Mth	Day	DAP	Sam†	Dry Weight: Pod: Immat.‡	Pod: Mature	Pod: Total	Seed	Dropped Pod	Percent Shelling
				g m^{-2}					%
				Fungicide Treated					
6	25	23	B	0.0	0.0	0.0	0.0	0.0	.
7	9	37	B	0.0	0.0	0.0	0.0	0.0	.
7	23	51	B	1.3	0.0	1.3	0.0	0.0	0.0
7	30	58	P	6.6	0.0	6.6	0.0	0.0	0.0
8	6	65	B	10.8	13.8	24.7	5.5	0.0	20.7
8	18	77	P	13.3	54.4	67.8	26.4	0.0	36.1
8	20	79	B	11.2	87.7	99.0	48.5	0.0	48.8
8	26	85	P	9.8	137.5	147.3	90.0	0.0	60.6
9	3	93	B	10.8	205.4	216.2	144.8	0.0	67.0
9	11	101	P	26.4	316.4	342.8	237.5	0.0	69.3
9	17	107	B	7.5	330.5	338.1	247.7	0.0	73.0
9	23	113	P	15.1	449.0	464.1	349.2	0.0	75.5
10	1	121	B	14.1	429.8	444.0	334.3	1.0	75.1
10	7	127	P	7.6	532.8	540.5	416.8	1.1	77.1
10	15	135	B	14.4	538.3	552.7	441.2	15.9	79.6
10	21	141	P	17.1	533.1	550.3	428.9	18.0	77.9
10	29	149	B	9.0	564.8	573.9	463.8	45.1	80.7
				Not Treated					
6	25	23	B	0.0	0.0	0.0	0.0	0.0	.
7	9	37	B	0.0	0.0	0.0	0.0	0.0	.
7	23	51	B	0.6	0.0	0.6	0.0	0.0	0.0
7	30	58	P	8.9	0.0	8.9	0.0	0.0	0.0
8	6	65	B	15.6	7.8	23.5	3.3	0.0	12.8
8	18	77	P	14.2	79.4	93.6	43.6	0.0	44.9
8	20	79	B	8.1	81.3	89.4	41.8	0.0	46.3
8	26	85	P	15.3	140.1	155.4	91.4	0.0	58.9
9	3	93	B	9.2	192.3	201.5	143.7	0.0	71.0
9	11	101	P	9.5	244.2	253.7	193.2	0.0	76.2
9	17	107	B	8.1	333.0	341.2	258.8	0.0	75.7
9	23	113	P	12.4	376.5	389.0	297.2	0.0	76.4
10	1	121	B	5.1	361.0	366.1	292.1	5.6	79.5
10	7	127	P	8.7	422.9	431.6	347.7	9.3	80.6
10	15	135	B	2.2	274.3	276.6	230.0	111.0	83.1
10	21	141	P	3.7	261.1	264.8	219.5	179.0	82.8
10	29	149	B	0.5	13.1	13.6	11.1	240.2	62.0

† Sampling method: B = Biomass (1 m of row, 2 treatments, 4 blocks);
P = Photosynthesis (0.61 m of row, 2 treatments, 2 blocks).

‡ Immature pods: pods that shrunk after drying.

Table A-5 -- continued.

Mth	Day	DAP	Sam†	Percentage Disease	Percentage Defol.	Disease Severity Observed	Disease Severity Transf.‡	HAD§	HAA¶
				%				d	MJ m^{-2}
					Fungicide Treated				
6	25	23	B	0.00	0.00	0.00	.	1.9	22.0
7	9	37	B	0.00	0.00	0.00	.	11.9	122.9
7	23	51	B	0.00	4.04	4.04	-1.17	37.3	328.8
7	30	58	P	0.00	0.77	0.77	-1.58		
8	6	65	B	0.00	1.59	1.59	-1.42	93.4	633.2
8	18	77	P	0.00	5.43	5.43	-1.07		
8	20	79	B	0.00	1.74	1.74	-1.40	177.6	980.4
8	26	85	P	0.00	0.70	0.70	-1.60		
9	3	93	B	0.02	1.44	1.46	-1.44	276.0	1321.4
9	11	101	P	0.00	2.00	2.00	-1.36		
9	17	107	B	0.08	2.53	2.61	-1.29	376.8	1641.4
9	23	113	P	0.01	1.11	1.12	-1.50		
10	1	121	B	0.06	1.60	1.66	-1.41	471.9	1934.6
10	7	127	P	0.07	14.71	14.76	-0.65		
10	15	135	B	0.13	6.84	6.96	-0.98	551.7	2190.4
10	21	141	P	0.57	8.71	9.25	-0.87		
10	29	149	B	0.15	12.40	12.55	-0.73	616.3	2422.2
					Not Treated				
6	25	23	B	0.00	0.00	0.00	.	1.9	22.0
7	9	37	B	0.00	0.00	0.00	.	11.9	122.9
7	23	51	B	0.00	3.27	3.28	-1.23	37.1	327.9
7	30	58	P	0.00	9.31	9.31	-0.86		
8	6	65	B	0.00	0.00	0.00	-2.44	91.2	629.1
8	18	77	P	0.25	8.61	8.84	-0.89		
8	20	79	B	0.28	7.24	7.49	-0.95	170.2	971.0
8	26	85	P	1.49	15.05	16.35	-0.59		
9	3	93	B	4.22	47.65	49.87	0.36	240.7	1279.1
9	11	101	P	5.05	70.57	72.15	1.12		
9	17	107	B	4.77	69.23	70.69	1.06	283.1	1505.8
9	23	113	P	4.15	76.86	77.80	1.38		
10	1	121	B	4.88	82.07	82.95	1.68	300.6	1620.5
10	7	127	P	9.17	70.63	73.32	1.17		
10	15	135	B	7.89	97.43	97.69	3.76	304.3	1648.4
10	21	141	P	.	100.00	100.00	.		
10	29	149	B	.	100.00	100.00	.	304.5	1650.3

† Sampling method: B = Biomass (1 m of row, 2 treatments, 4 blocks); P = Photosynthesis (0.61 m of row, 2 treatments, 2 blocks).

‡ Transformation with the Gompertz function: -ln[-ln(y)]; The value y is the proportion of disease severity, i.e. between 0 and 1.

§ Cumulative healthy leaf area duration (Waggoner and Berger, 1987).

¶ Cumulative healthy leaf area absorption (Waggoner and Berger, 1987).

Table A-6. Growth analysis data and disease assessment for summer of 1987.

Mth	Day	DAP	Sam†	Growth Stage Veg.	Growth Stage Rep.	Dry Weight Biomass	Dry Weight Stem	Dry Weight Leaf	Specific Leaf Area	Leaf Area Index
						g m^{-2}			cm^2 g^{-1}	m^2 m^{-2}
					Fungicide Treated					
6	24	22	B	7.1	0	22.7	9.8	12.9	224.5	0.29
7	8	36	B	11.3	2	92.4	41.4	50.9	205.3	1.04
7	22	50	B	14.9	4	277.6	139.8	132.6	206.6	2.74
7	28	56	P	15.6	5	354.0	188.6	156.0	174.8	2.72
8	5	64	B	18.2	5	515.3	243.8	198.6	198.9	3.96
8	11	70	P	18.3	6	561.1	242.9	194.5	188.6	3.68
8	19	78	B	20.8	6	699.3	292.3	221.8	214.1	4.76
8	26	85	P	22.2	7	856.1	304.1	247.5	191.2	4.74
9	1	91	B	22.5	7	919.2	353.3	258.3	210.5	5.44
9	1	91	P	22.5	7	839.7	275.9	221.2	204.3	4.52
9	8	98	P	23.5	7	916.0	300.9	235.4	210.8	4.96
9	15	105	B	25.0	7	1062.6	341.7	254.0	212.9	5.41
9	22	112	P	24.2	7	1046.8	361.5	258.2	177.1	4.58
9	29	119	B	24.9	7	1248.1	377.6	267.0	184.0	4.91
10	6	126	P	25.3	7	1127.3	361.4	250.1	169.6	4.24
10	13	133	B	24.8	8	1304.3	413.6	257.6	190.3	4.87
10	20	140	P	24.2	8	1361.6	376.5	275.0	182.1	5.01
10	27	147	B	24.8	8	1301.3	446.0	244.8	182.9	4.49
					Not Treated					
6	24	22	B	7.1	0	22.7	9.8	12.9	224.5	0.29
7	8	36	B	11.3	2	92.4	41.4	50.9	205.3	1.04
7	22	50	B	14.3	3	256.1	130.8	124.0	199.1	2.47
7	28	56	P	16.1	5	389.4	199.4	164.3	201.8	3.31
8	5	64	B	18.3	5	485.5	235.2	189.2	199.6	3.76
8	11	70	P	19.0	6	600.0	254.6	200.6	182.8	3.66
8	19	78	B	20.8	6	625.5	266.5	178.1	207.1	3.69
8	26	85	P	21.6	7	646.3	271.8	127.6	181.2	2.31
9	1	91	B	22.8	7	667.7	294.6	107.8	202.9	2.19
9	1	91	P	23.2	7	693.4	267.8	87.7	193.2	1.69
9	8	98	P	24.3	7	730.2	267.0	95.3	180.4	1.73
9	15	105	B	24.8	7	616.1	244.2	27.9	190.0	0.53
9	22	112	P	22.1	8	623.9	244.1	0.0	.	0.00
9	29	119	B	.	8	546.9	248.1	0.0	.	0.00
10	6	126	P	.	9	265.4	191.9	0.0	.	0.00
10	13	133	B	.	9	323.9	242.9	0.0	.	0.00
10	20	140	P	.	9	222.3	177.4	0.0	.	0.00
10	27	147	B	.	9	229.2	210.4	0.0	.	0.00

† Sampling method: B = Biomass (1 m of row, 2 treatments, 4 blocks); P = Photosynthesis (0.61 m of row, 2 treatments, 2 blocks).

Table A-6 -- continued.

Mth	Day	DAP	Sam†	Percent Light		Pod Number			Seed Number	Seeds per Pod
				Interc.	Absorb.	Immat.‡	Mature	Total		
				%		m^{-2}				
					Fungicide Treated					
6	24	22	B	10.9	7.4§	0	0	0	0	.
7	8	36	B	54.2	50.7§	0	0	0	0	.
7	22	50	B	83.5	79.5	79	0	79	0	.
7	28	56	P	83.5	79.5	98	0	98	0	.
8	5	64	B	91.6	88.5	279	0	279	0	.
8	11	70	P	88.1	84.1	348	0	348	0	.
8	19	78	B	97.6	94.1	448	0	448	0	.
8	26	85	P	.	.	374	80	454	145	1.82
9	1	91	B	97.7	94.6	403	90	494	172	1.90
9	1	91	P	97.5	94.5	411	94	505	174	1.85
9	8	98	P	.	.	431	152	583	283	1.87
9	15	105	B	97.2	94.2	413	211	625	390	1.84
9	22	112	P	.	.	434	158	592	302	1.91
9	29	119	B	97.0	93.3	388	305	694	559	1.83
10	6	126	P	96.6	92.7	250	213	464	439	2.06
10	13	133	B	97.0	91.7	255	367	622	636	1.73
10	20	140	P	93.4	87.8	214	349	563	654	1.88
10	27	147	B	.	.	325	329	655	597	1.81
					Not Treated					
6	24	22	B	10.9	7.4§	0	0	0	0	.
7	8	36	B	54.2	50.7§	0	0	0	0	.
7	22	50	B	79.0	75.0	48	0	48	0	.
7	28	56	P	86.3	82.5	169	0	169	0	.
8	5	64	B	92.7	89.8	220	0	220	0	.
8	11	70	P	87.2	83.6	339	0	339	0	.
8	19	78	B	95.3	92.2	365	0	365	0	.
8	26	85	P	.	.	369	41	410	76	1.86
9	1	91	B	87.1	84.1	285	90	375	173	1.92
9	1	91	P	86.7	83.8	325	120	446	241	2.00
9	8	98	P	70.0	66.0	298	150	449	295	1.96
9	15	105	B	59.6	55.8	242	159	401	305	1.92
9	22	112	P	.	.	195	218	413	390	1.79
9	29	119	B	34.1	28.3	128	139	267	258	1.86
10	6	126	P	31.8	25.7	10	16	26	31	1.95
10	13	133	B	28.8	20.8	4	18	23	36	1.95
10	20	140	P	27.0	19.1	0	9	9	17	1.99
10	27	147	B	.	.	0	3	3	6	1.89

† Sampling method: B = Biomass (1 m of row, 2 treatments, 4 blocks); P = Photosynthesis (0.61 m of row, 2 treatments, 2 blocks).
‡ Immature pods: pods that shrunk after drying.
§ Light absorption was corrected for the reflection from the soil. A 3.5% reflection from the canopy was assumed.

Table A-6 -- continued.

Mth	Day	DAP	Sam†	Dry Weight: Pod: Immat.‡	Pod: Mature	Pod: Total	Seed	Dropped Pod	Percent Shelling
				g m^{-2}					%
				Fungicide Treated					
6	24	22	B	0.0	0.0	0.0	0.0	0.0	.
7	8	36	B	0.0	0.0	0.0	0.0	0.0	.
7	22	50	B	5.1	0.0	5.1	0.0	0.0	0.0
7	28	56	P	9.3	0.0	9.3	0.0	0.0	0.0
8	5	64	B	24.4	48.4	72.8	21.6	0.0	29.4
8	11	70	P	15.4	108.2	123.6	46.5	0.0	37.2
8	19	78	B	15.6	169.5	185.2	106.9	0.0	57.7
8	26	85	P	10.7	293.6	304.4	203.4	0.0	66.5
9	1	91	B	14.2	293.3	307.6	210.8	0.0	67.8
9	1	91	P	10.4	332.1	342.5	249.1	0.0	72.7
9	8	98	P	13.4	366.1	379.6	283.8	0.0	74.7
9	15	105	B	21.3	445.4	466.8	345.1	0.0	73.8
9	22	112	P	11.8	415.1	427.0	300.5	0.0	70.0
9	29	119	B	17.9	585.6	603.5	453.8	0.0	75.0
10	6	126	P	8.7	507.0	515.7	383.0	4.0	74.1
10	13	133	B	8.0	624.9	633.0	491.1	7.6	77.5
10	20	140	P	5.4	704.6	710.0	555.0	19.2	78.2
10	27	147	B	13.8	593.2	610.4	478.6	27.6	78.7
				Not Treated					
6	24	22	B	0.0	0.0	0.0	0.0	0.0	.
7	8	36	B	0.0	0.0	0.0	0.0	0.0	.
7	22	50	B	1.3	0.0	1.3	0.0	0.0	0.0
7	28	56	P	19.7	5.8	25.6	1.5	0.0	5.4
8	5	64	B	17.3	43.6	61.0	17.2	0.0	26.9
8	11	70	P	13.5	131.2	144.7	66.4	0.0	45.9
8	19	78	B	8.2	172.5	180.8	114.6	0.0	63.3
8	26	85	P	13.3	233.4	246.7	166.9	0.0	67.1
9	1	91	B	8.1	257.1	265.2	190.2	0.0	71.7
9	1	91	P	6.9	330.8	337.8	256.9	0.0	76.0
9	8	98	P	10.0	357.8	367.9	275.0	0.0	74.6
9	15	105	B	4.8	339.1	344.0	265.1	0.0	76.9
9	22	112	P	2.0	377.7	379.7	305.1	0.0	80.2
9	29	119	B	0.6	298.1	298.8	240.7	37.2	80.4
10	6	126	P	0.1	27.7	73.5	22.4	240.4	80.2
10	13	133	B	0.1	27.5	80.9	22.6	241.5	81.6
10	20	140	P	0.0	12.9	44.8	10.6	290.8	82.2
10	27	147	B	0.0	4.4	18.8	3.7	290.0	62.7

† Sampling method: B = Biomass (1 m of row, 2 treatments, 4 blocks);
P = Photosynthesis (0.61 m of row, 2 treatments, 2 blocks).
‡ Immature pods: pods that shrunk after drying.

Table A-6 -- continued.

Mth	Day	DAP	Sam†	Percentage Disease	Defol.	Disease Severity Observed	Transf.‡	HAD§	HAA¶
				%				d	MJ m^{-2}
				Fungicide Treated					
6	24	22	B	0.00	0.00	0.00	.	1.7	20.1
7	8	36	B	0.00	0.65	0.65	-1.62	11.1	115.7
7	22	50	B	0.00	0.51	0.51	-1.66	37.6	324.2
7	28	56	P	0.00	0.41	0.41	-1.70		
8	5	64	B	0.00	0.78	0.78	-1.58	84.5	617.9
8	11	70	P	0.09	0.37	0.46	-1.68		
8	19	78	B	0.08	1.16	1.24	-1.48	145.6	934.8
8	26	85	P	0.03	0.74	0.77	-1.58		
9	1	91	B	0.04	0.65	0.69	-1.60	211.8	1231.6
9	1	91	P	0.02	1.18	1.20	-1.49		
9	8	98	P	0.08	0.67	0.74	-1.59		
9	15	105	B	0.09	0.93	1.02	-1.52	287.8	1536.2
9	22	112	P	0.08	0.88	0.96	-1.54		
9	29	119	B	0.07	2.03	2.10	-1.35	360.1	1814.3
10	6	126	P	0.05	0.27	0.32	-1.75		
10	13	133	B	0.16	2.56	2.72	-1.28	428.6	2065.1
10	20	140	P	0.29	0.88	1.17	-1.49		
10	27	147	B	0.28	8.53	8.79	-0.89	494.0	2301.2
				Not Treated					
6	24	22	B	0.00	0.00	0.00	.	1.7	20.1
7	8	36	B	0.00	0.65	0.65	-1.62	11.1	115.7
7	22	50	B	0.00	2.37	2.37	-1.32	35.7	316.6
7	28	56	P	0.00	4.12	4.12	-1.16		
8	5	64	B	0.12	4.97	5.08	-1.09	79.4	599.4
8	11	70	P	0.45	6.63	7.06	-0.97		
8	19	78	B	1.43	21.26	22.37	-0.40	131.2	896.5
8	26	85	P	3.54	51.69	53.39	0.47		
9	1	91	B	2.97	57.73	58.97	0.64	168.8	1125.0
9	1	91	P	4.10	53.41	55.30	0.52		
9	8	98	P	3.49	63.02	64.34	0.82		
9	15	105	B	4.98	81.11	82.03	1.62	187.3	1255.6
9	22	112	P	.	100.00	100.00	.		
9	29	119	B	.	100.00	100.00	.	190.8	1285.4
10	6	126	P	.	100.00	100.00	.		
10	13	133	B	.	100.00	100.00	.	190.8	1285.4
10	20	140	P	.	100.00	100.00	.		
10	27	147	B	.	100.00	100.00	.	190.8	1285.4

† Sampling method: B = Biomass (1 m of row, 2 treatments, 4 blocks); P = Photosynthesis (0.61 m of row, 2 treatments, 2 blocks).
‡ Transformation with the Gompertz function: -ln[-ln(y)]; The value y is the proportion of disease severity, i.e. between 0 and 1.
§ Cumulative healthy leaf area duration (Waggoner and Berger, 1987).
¶ Cumulative healthy leaf area absorption (Waggoner and Berger, 1987).

Table A-7. Yield and quality analysis of the final harvests for fungicide-treated and non-treated Florunner peanut grown during summers of 1986 and 1987.

Parameter	Harvest 1			Harvest 2		
	Fungic. Treated	Not Treated	F	Fungic. Treated	Not Treated	F
	1986 (126 DAP)			1986 (140 DAP)		
Dropped Pod Yld†	8.3	13.2	1.7	242.4	1352.9	31.7 *
Pod Yield†	4980.8	3666.1	26.8 *	5248.8	2206.3	66.3 *
Seed Yield†	3839.9	2989.6	22.3 *	4163.3	1832.3	52.6 *
Shelling Percent	77.1	81.5	64.3 **	79.2	83.0	49.7 **
Number of Pods‡	474.7	303.0	84.0 **	474.8	190.2	144.9 **
Number of Seeds‡	735.3	527.9	40.0 **	739.0	327.8	97.3 **
Seeds per Pod	1.5	1.7	18.1 *	1.5	1.7	13.5 *
Weight per Seed§	0.6	0.5	13.7 *	0.6	0.6	0.4
ELK Percentage¶	42.2	38.6	0.4	52.9	45.7	1.1
SMK Percentage¶	50.2	56.3	1.1	41.1	49.5	2.1
SS Percentage¶	1.9	1.8	0.0	2.5	2.1	1.7
OK Percentage¶	6.3	2.8	460.5 **	3.7	2.6	2.5
	1987 (122 DAP)			1987 (136 DAP)		
Dropped Pod Yld†	11.5	1406.4	157.6 **	27.0	2321.3	324.4 **
Pod Yield†	5441.8	1673.9	225.0 **	5843.1	572.3	944.4 **
Seed Yield†	4124.6	1319.4	230.7 **	4448.9	454.1	675.8 **
Shelling Percent	75.8	78.8	81.3 **	76.1	79.2	24.2 *
Number of Pods‡	485.4	144.3	678.7 **	501.0	59.8	975.0 **
Number of Seeds‡	751.8	249.3	509.6 **	778.4	97.3	1175.2 **
Seeds per Pod	1.5	1.7	61.1 **	1.5	1.6	4.1
Weight per Seed§	0.6	0.5	266.1 **	0.6	0.5	22.7 *
ELK Percentage¶	56.7	32.0	37.5 **	52.2	28.8	29.8 *
SMK Percentage¶	33.9	61.0	60.4 **	38.8	60.6	40.4 **
SS Percentage¶	3.5	1.7	4.8	4.1	2.6	7.5
OK Percentage¶	5.6	5.0	0.4	4.6	7.7	6.7

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

† Yields are expressed in $kg\ ha^{-1}$.

‡ Numbers are expressed in m^{-2}.

§ The weight per seed is expressed in g, and includes seeds from ELK and SMK.

¶ ELK (Extra Large Kernels), SMK (Sound Mature Kernels), SS (Sound Split), and OK (Other Kernels).

APPENDIX B

USE OF RICHARDS EQUATION TO DESCRIBE DISEASE PROGRESS

Richards (1959; 1969) published a flexible growth function to describe empirically the growth or development of biological organisms:

$$\frac{dW}{dt} = \frac{kW}{1-m}\left[(A/W)^{(1-m)} - 1\right] \qquad (m \geq 0,\ m \neq 1) \quad [1]$$

Here W represents the size at time t and A its ultimate limiting value, k is the 'rate constant' which determines the spread of the curve along the time axis, and m is the factor determining the shape of the curve. The constants k and A are positive, and m is always positive, since a negative value is non-physiological, giving infinite growth rates as W approaches zero (France and Thornley, 1984). The Richards function was mathematically transformed to be used as a standard function of plant epidemiology by Jowett *et al.* (1974) and Madden (1980) to describe disease progress with time. However, both sources give incorrect or incomplete equations which cause many problems in the utilization of the Richards function in plant epidemiology.

The function [1] can be transformed to be used in plant epidemiology to the following function:

$$\frac{dy}{dt} = \frac{ry}{m-1}\left[1 - (y/y_{max})^{(m-1)}\right] \qquad (m \geq 0;\ m \neq 1) \quad [2]$$

where: $r = k$; $y = W$; $y_{max} = A$

Here y represents the proportion of disease, y_{max} the ultimate limiting proportion of disease (usually 1), and r the disease-progress rate. The three functions most commonly use in plant epidemiology are the monomolecular, logistic, and Gompertz functions. All of these functions can be obtained by selecting appropriate values of m in the Richards function. The monomolecular function, $dy/dt = r(y_{max}-y)$ is obtained when $m = 0$, and the logistic function, $dy/dt = ry[1-(y/y_{max})]$ when $m = 2$. The Gompertz function, $dy/dt = ry[-\ln(y/y_{max})]$ is obtained when m approaches 1 (Richards, 1959; 1969; Causton *et al.*, 1978). Obviously there are many other curves that can be obtained with the Richards function with different values of m.

When the Richards function is fitted to a set of disease-progress values, difficulties may arise in finding the best m value. This can be achieved by transforming the data with the linear form of the Richards function and by regressing the transformed disease proportions against time. Integrating the Richards function [2] yields:

$$y = y_{max}\,[1 \pm B \exp(-rt)]^{1/(1-m)} \qquad (m\geq 0,\ m\neq 1) \quad [3]$$

$$\text{where } B = y_0^{(1-m)} - 1$$

The (+) sign within the brackets is applicable when $m > 1$ and the (-) sign when $0 \leq m < 1$ (Richards, 1959; 1969; Causton, 1969; Causton *et al.*, 1978). After a few mathematical transformations, the following functions, which have the form of a linear regression ($x_d = b_0 + b_1x_1$), are obtained:

$$\ln\{1 / [(y/y_{max})^{(1-m)} - 1]\} = -\ln(B) + rt \qquad (y\neq 0,1;\ m>1) \quad [4]$$

$$\ln\{1 / [1 - (y/y_{max})^{(1-m)}]\} = -\ln(B) + rt \qquad (y\neq 1;\ 0\leq m<1) \quad [5]$$

By using the concept of absolute values, these last two functions can commonly be expressed with the following linear form (Causton, 1969):

$$\ln\left|1 / [(y/y_{max})^{(1-m)} - 1]\right| = -\ln(B) + rt \qquad (y\neq 1;\ m\geq 0,\ m\neq 1) \quad [6]$$

Disease severity of late leafspot on Florunner peanuts was assessed during summer 1986 (Table A-5) and summer 1987 (Table A-6). The disease severities at each day after planting were transformed with the linear form of the Richards function [6] and regressed against days after planting. As suggested by the function [4], disease severities of 0 and 1 were not included in the linear regression. The final m value selected was the one that gave the highest coefficient of determination in the linear regression (Table B-1). In 1986 and 1987, the best m value was 0.87 and 2.48, respectively.

In some instances, when m is smaller than 1, the expression B exp(-rt) in function [3] may be smaller than -1. The solution of y, in this situation, is an imaginary number, but we can let y = 0 until t is large enough to make the expression B exp(-rt) greater than -1 (Table B-1). The value of t when this last expression equals -1 represents the time at which the disease begins to progress.

The value of r obtained depends on the value of m. Richards (1959) proposed other parameters to describe the growth of biological organisms. These parameters can be used to improve the usefulness of the rate of disease progress (r) in the interpretation of differences between values of r when the r-values are derived from curves of different forms. The other parameters that were proposed are the weighted mean relative rate of disease progress over the whole period of disease development (r/m), and the weighted mean absolute rate of disease progress [$y_{max}r/(2m + 2)$]. These parameters allow comparison between curves with different values of m (Table B-1). The four parameters B, m, r/m, and $y_{max}r/(2m + 2)$ define the disease progress curves completely, and allow comparisons of average rates of disease progress.

Table B-1. Estimation of parameters in the Richards function for values of m lower and higher than 1. Linear regressions were applied on disease severity data collected on Florunner peanut during 1986 and 1987 in Gainesville, Florida.

Parameter measured or estimated	Result obtained in 1986	Result obtained in 1987
From linear regression ($x_d = b_0 + b_1x_1$)†		
Best coeff. of determination (R^2)	0.8301	0.9771
Best m value obtained	0.87	2.48
Coefficient of x_1 (b_1)	0.0510	0.1270
Constant of the regression (b_0)	-2.3137	-12.0609
Derivation of parameters in Richards function‡		
Rate of disease progress (r)	0.0510	0.1270
Constant of integration (B)	10.1118	1.730×10^5
From the estimated Richards function		
Value of y when t=0	n.a.§	2.889×10^{-4}
Value of t when B exp(-rt) = -1	45.3667	n.a.§
Value of t when y=0.01	61.0	41.3
Mean relative progress rate¶	0.0586	0.0512
Mean absolute progress rate#	0.0136	0.0182

† $x_d = \ln \left|1 / [(y/y_{max})^{(1-m)} - 1]\right|$, where $y \neq 0,1$; $m \geq 0$, $m \neq 1$.

‡ $y = y_{max} [1 \pm B \exp(-rt)]^{1/(1-m)}$, where $B = y_0^{(1-m)} - 1$. The (+) sign within the brackets is used when $m > 1$ and the (-) sign when $0 \leq m < 1$.

§ Not applicable; leading to an imaginary mathematical solution.

¶ Weighted mean relative rate of disease progress over the whole period of disease development (r/m).

Weighted mean absolute rate of disease progress $[y_{max}r/(2m + 2)]$.

APPENDIX C

LEAFLET AND CANOPY PHOTOSYNTHESIS

Table C-1. Carbon exchange rate (CER) of peanut leaflets that were tagged in fungicide-treated and non-treated plots in Gainesville, Florida in 1986 and 1987.

Mth	Day	DAP	Leaf Age	Blk	Fung. Treated CER	Fung. Treated Necrotic Area	Not Treated CER	Not Treated Necrotic Area	Percentage of CER in fungicide-treated plots
			d		mg $m^{-2}s^{-1}$	%	mg $m^{-2}s^{-1}$	%	%
					Tagged on 31 August 1986				
9	6	96	6	1	0.86	0.0	1.06	0.0	123.7
				2	0.95	0.0	1.16	0.0	122.0
				3	0.94	0.0	1.14	0.0	121.1
				4	1.18	0.0	0.99	0.0	83.9
9	13	103	13	1	1.09	0.0	0.77	1.1	70.6
				2	0.78	0.0	0.80	0.5	103.0
				3	0.78	0.0	1.08	0.3	138.2
				4	1.06	0.0	0.81	0.1	76.4
9	20	110	20	1	0.87	0.0	0.29	13.0	33.8
				2	0.93	0.0	0.29	18.6	31.3
				3	0.94	0.0	0.90	2.0	95.7
				4	0.83	0.0	0.48	10.3	57.8
9	27	117	27	1	0.98	0.0	0.78	7.4	79.7
				2	0.86	0.0	0.53	12.3	62.2
				3	1.01	0.0	0.48	7.8	47.1
				4	1.00	0.0	0.67	4.7	67.6
					Tagged on 4 August 1987				
8	18	77	14	1	1.33	0.0	1.14	0.1	85.2
				2	1.59	0.0	1.41	0.3	88.4
				3	1.29	0.0	1.12	0.0	87.0
				4	1.39	0.0	1.26	0.5	90.7

Table C-1 -- continued.

Mth	Day	DAP	Leaf Age	Blk	Fung. Treated CER	Fung. Treated Necrotic Area	Not Treated CER	Not Treated Necrotic Area	Percentage of CER in fungicide-treated plots
			d		mg $m^{-2}s^{-1}$	%	mg $m^{-2}s^{-1}$		%
				Tagged on 4 August 1987					
8	21	80	17	1	1.10	0.0	1.13	0.7	103.2
				2	1.25	0.0	1.18	0.2	94.3
				3	1.32	0.0	1.13	0.7	85.4
				4	1.30	0.0	1.16	1.0	88.8
8	26	85	22	1	1.17	0.0	0.84	1.7	71.5
				2	0.98	0.0	0.52	2.3	53.0
				3	1.14	0.0	0.54	1.5	47.5
				4	1.04	0.0	0.69	1.2	65.9
8	29	88	25	1	1.17	0.0	1.19	2.4	102.1
				2	1.01	0.0	0.35	1.9	35.0
				3	1.05	0.0	1.03	2.4	98.6
				4	1.06	0.0	1.04	4.1	97.9
9	5	95	32	1	0.76	0.0	0.71	4.0	93.0
				3	1.18	0.0	0.39	13.8	33.5
				4	1.14	0.0	0.68	14.1	59.5
				Tagged on 18 August 1987					
8	26	85	8	1	1.20	0.0	1.30	0.0	108.2
				2	0.92	0.0	0.98	0.3	107.5
				3	1.11	0.0	0.58	0.0	52.3
				4	1.15	0.0	1.22	0.0	105.4
8	29	88	11	1	1.32	0.0	1.24	1.1	93.7
				2	1.20	0.0	1.31	0.0	109.5
				3	1.29	0.0	1.42	0.0	110.2
				4	1.07	0.0	1.30	0.0	121.4
9	5	95	18	1	1.19	0.0	1.01	2.0	84.6
				2	1.34	0.0	1.02	1.7	75.6
				3	1.20	0.0	1.29	0.1	107.2
				4	1.22	0.0	0.99	0.5	81.7
9	15	105	28	1	1.28	0.0	0.48	8.1	37.7
				2	1.12	0.0	0.72	5.1	64.6
				3	1.06	0.0	0.85	1.9	80.5
				4	1.21	0.0	0.27	16.0	22.4

Table C-1 -- continued.

Mth	Day	DAP	Leaf Age	Blk	Fung. Treated CER	Fung. Treated Necrotic Area	Not Treated CER	Not Treated Necrotic Area	Percentage of CER in fungicide-treated plots
			d		mg $m^{-2}s^{-1}$	%	mg $m^{-2}s^{-1}$	%	%
					Tagged on 3 September 1987				
9	15	105	12	1	0.98	0.0	0.81	3.5	82.2
				2	0.86	0.0	0.88	4.2	101.8
				3	1.31	0.0	0.73	2.9	56.1
				4	1.08	0.0	0.60	3.0	55.7

Table C-2. Carbon exchange rate (CER) that was measured on peanut canopies exposed to different photosynthetic photon flux densities (PPFD) during 1986 in Gainesville, Florida.

				Fungicide Treated			Not Treated		
Mth	Day	DAP	Rep	LAI	PPFD	CER	LAI	PPFD	CER
					μmole $m^{-2}s^{-1}$	mg $m^{-2}s^{-1}$		μmole $m^{-2}s^{-1}$	mg $m^{-2}s^{-1}$
7	30	58	1	3.24	1664	1.27	3.49	1730	1.33
					837	0.54		810	0.57
					406	-0.01		378	-0.01
					0	-0.62		0	-0.55
			2	3.08	1567	1.30	4.57	1651	1.55
					786	0.55		810	0.84
					393	0.12		378	0.18
					0	-0.58		0	-0.72
8	18	77	1	6.63	2000	1.72	6.80	1889	1.43
					699	0.73		908	0.63
					432	0.17		422	0.11
					0	-0.42		0	-0.54
			2	5.61	1810	1.31	6.82	1922	1.22
					858	0.95		954	0.81
					405	0.29		456	-0.11
					0	-0.39		0	-0.54
			3	4.67	1653	1.38	4.91	1989	1.26
					680	0.72		900	0.85
					285	0.46		404	0.33
					0	-0.44		0	-0.30
8	26	85	1	8.74	1820	1.17	6.38	1788	1.03
					814	0.62		641	0.30
					377	0.13		423	0.15
					0	-0.49		0	-0.65
			2	7.32	1759	1.30	6.12	1834	1.13
					615	0.41		631	0.40
					395	0.18		399	0.17
					0	-0.52		0	-0.69
			3	5.94	1789	0.93	5.32	1681	0.91
					637	0.20		611	0.19
					429	-0.05		408	0.10
					0	-0.64		0	-0.62
9	11	101	1	7.03	1860	1.70	1.94	1799	0.55
					866	1.06		621	0.11
					412	0.18		402	-0.21
					0	-0.53		0	-0.88
			2	8.47	1970	1.45	2.74	1925	0.81
					962	0.96		890	0.35
					208	-0.22		222	-0.40
					0	-0.56		0	-0.69

Table C-2 -- continued

Mth	Day	DAP	Rep	Fungicide Treated			Not Treated		
				LAI	PPFD	CER	LAI	PPFD	CER
					μmole $m^{-2}s^{-1}$	mg $m^{-2}s^{-1}$		μmole $m^{-2}s^{-1}$	mg $m^{-2}s^{-1}$
9	23	113	1	7.11	1733	1.33	1.76	1684	0.36
					808	0.66		810	0.14
					390	0.16		394	-0.22
					0	-0.39		0	-0.62
			2	9.00	1694	0.97	1.74	1668	0.31
					844	0.56		806	0.16
					406	0.06		380	-0.15
					0	-0.59		0	-0.65
10	7	127	1	4.89	1548	0.52	0.41	1566	0.02
					755	0.18		750	-0.02
					359	-0.08		378	-0.14
					0	-0.51		0	-0.24
			2	4.17	1518	0.76	0.40	1616	-0.05
					716	0.38		750	-0.02
					311	0.02		377	-0.03
					0	-0.34		0	-0.34
10	21	141	1	4.66	1509	0.35	0.02	1472	-0.04
					710	0.29		737	-0.08
					355	0.04		362	-0.17
					0	-0.26		0	-0.16
			2	5.04	1381	0.57	0.06	1484	-0.08
					693	0.33		690	-0.05
					354	0.10		341	-0.09
					0	-0.33		0	-0.11

Table C-3. Carbon exchange rate (CER) that was measured on peanut canopies exposed to different photosynthetic photon flux densities (PPFD) during 1987 in Gainesville, Florida.

				Fungicide Treated			Not Treated		
Mth	Day	DAP	Rep	LAI	PPFD	CER	LAI	PPFD	CER
					μmole $m^{-2}s^{-1}$	mg $m^{-2}s^{-1}$		μmole $m^{-2}s^{-1}$	mg $m^{-2}s^{-1}$
7	28	56	1	2.76	2058	1.18	3.21	1938	1.14
					989	0.61		900	0.62
					440	0.08		406	0.12
					0	-0.51		0	-0.57
			2	2.70	1950	1.18	3.42	1914	1.18
					993	0.60		806	0.64
					461	0.09		361	0.09
					0	-0.52		0	-0.63
8	11	70	1	4.21	1763	1.12	3.51	1781	0.77
					836	0.58		893	0.37
					389	0.09		348	-0.04
					0	-0.49		0	-0.57
			2	3.15	1794	0.85	3.82	1723	0.80
					886	0.41		896	0.42
					425	0.09		408	0.04
					0	-0.47		0	-0.52
8	26	85	1	5.33	1819	1.47	2.59	1780	1.01
					823	0.69		833	0.48
					623	0.56		389	0.01
					0	-0.62		0	-0.73
			2	4.17	2059	1.36	2.04	1820	0.77
					976	0.71		902	0.27
					376	0.06		417	-0.05
					0	-0.52		0	-0.56
9	1	91	1	4.91	1835	0.86	1.75	1729	0.94
					920	0.46		862	0.54
					417	0.03		301	-0.01
					0	-0.59		0	-0.54
			2	4.13	2124	1.10	1.64	1891	0.48
					1040	0.67		940	0.27
					260	-0.01		355	-0.05
					0	-0.54		0	-0.51
9	8	98	1	5.25	2074	1.36	1.10	1970	0.48
					947	0.71		1021	0.31
					486	0.22		443	0.06
					0	-0.46		0	-0.38
			2	4.68	1870	0.94	2.37	1910	0.51
					998	0.64		982	0.28
					413	0.13		472	0.09
					0	-0.40		0	-0.48

Table C-3 -- continued

Mth	Day	DAP	Rep	Fungicide Treated			Not Treated		
				LAI	PPFD	CER	LAI	PPFD	CER
					μmole $m^{-2}s^{-1}$	mg $m^{-2}s^{-1}$		μmole $m^{-2}s^{-1}$	mg $m^{-2}s^{-1}$
9	22	112	1	4.15	1715	1.08	0.00	-	-
					884	0.57		780	-0.04
					402	0.11		325	-0.09
					0	-0.42		0	-0.18
			2	5.02	1847	1.18	0.00	1726	-0.09
					933	0.74		764	-0.10
					411	0.15		357	-0.10
					0	-0.42		0	-0.13
10	6	126	1	4.20	1679	0.53	0.00	1748	-0.25
					822	0.26		830	-0.23
					371	0.02		380	-0.23
					0	-0.35		0	-0.23
			2	4.28	1848	0.46	0.00	1807	-0.09
					934	0.30		-	-
					422	0.05		-	-
					0	-0.34		0	-0.09
10	20	140	1	4.59	1840	0.51	0.00	1701	-0.06
					904	0.31		-	-
					379	0.02		-	-
					0	-0.41		0	-0.05
			2	5.43	1846	0.83	0.00	1734	-0.01
					864	0.52		-	-
					375	0.07		-	-
					0	-0.43		0	-0.06

Table C-4. Apparent canopy photosynthesis (ACP), dark respiration, observed and predicted maximum leaf photosynthesis (LFMAX), and percent nitrogen of the leaves that was measured on peanut canopies during 1986 and 1987 in Gainesville, Florida.

			Fungicide Treated					Not Treated				
			Obs. CER		LFMAX			Obs. CER		LFMAX		
Mth	Day	DAP	ACP	DARK	Obs.	Pred.	N	ACP	DARK	Obs.	Pred.	N
			—— mg CO_2 m^{-2} s^{-1} ——				%	—— mg CO_2 m^{-2} s^{-1} ——				%
						1986						
7	30	58	1.28	-0.60	0.95	1.72	4.26	1.44	-0.64	1.09	1.92	4.80
8	18	77	1.47	-0.42	0.83	1.41	3.96	1.30	-0.46	0.99	1.17	3.96
8	26	85	1.14	-0.55	0.95	1.11	3.79	1.02	-0.65	0.90	1.16	3.94
9	11	101	1.58	-0.55	1.00	1.64	3.44	0.68	-0.78	0.79	1.36	3.90
9	23	113	1.15	-0.49	0.91	1.07	3.68	0.33	-0.63	0.83	0.94	3.65
10	7	127	0.64	-0.42	0.73	0.62	3.12	-0.02	-0.29	0.32	0.88	3.96
10	21	141	0.46	-0.29	-	0.42	3.01	-0.06	-0.13	-	0.39	3.04
						1987						
7	28	56	1.18	-0.51	0.99	1.30	2.84	1.16	-0.60	1.01	1.35	3.11
8	11	70	0.98	-0.48	0.49	0.96	3.23	0.78	-0.55	0.57	0.84	3.28
8	26	85	1.42	-0.57	1.26	1.40	2.88	0.89	-0.64	1.15	1.38	3.30
9	1	91	0.98	-0.56	-	0.95	2.65	0.71	-0.52	-	1.37	3.22
9	8	98	1.15	-0.43	1.07	0.93	2.20	0.50	-0.43	1.00	0.92	3.38
9	22	112	1.13	-0.42	-	0.96	2.29	-0.09	-0.16	-	-	-
10	6	126	0.49	-0.34	0.56	0.41	2.40	-0.17	-0.16	-	-	-
10	20	140	0.67	-0.42	0.64	0.59	1.90	-0.04	-0.06	-	-	-

APPENDIX D

FORTRAN CODE OF THE LATE LEAFSPOT SUBROUTINES

Filename: COMDIS.DAT

```
      COMMON/CCON1/AVLEAR,DENLES,DISTMA,DISTSO,FEX1,FEX2,TAKOFF
      COMMON/CCOUT/GDISLA,GINFLA,GLATLA,GPOSLA,GPRELA,GSPOLA,GTOTLA,
     $     DSEVER,PERDEF,PERINF,PERDIS,CINDEX,SCOAIR,FCOAIR,XINDEX,
     $     CTEMFC,TOTLA1,TOTLA2,TOTLA3,TOTLA4,TOTLA5,TOTLA6,TOTLA7
      COMMON/CCRO1/DWLPOS,JDISWT,NDISRC,RACEID
      COMMON/CHUM1/PLCA,PLCB,PLCC,DPADJ,RHMAXC,RHMINI,RHMINS
      COMMON/CPAT1/CANHT,CONEFF,COPTT,CPDFAC,
     $     DEFHLT,DEFPRO,DFSMAX,DFSMIN,EXPFAC,FACSIT,FEX3,FEX4,FLN1,
     $     FRSUSC,IINF,ILAT,IPRE,PETFRA,PFUNGF,RICHI2,RICHM2,RICHR2,
     $     ZINCUB,ZINFEC,ZMATUR
      COMMON/CPAT3/WLCDOT,WSCDOT
      CHARACTER *25 RACEID
```

Filename: CONIDI.FOR

```
$STORAGE:2
C
C ***************************************************************************
C ***************************************************************************
C ***************************************************************************
C
      SUBROUTINE CONIDI
C
C ***************************************************************************
C ***************************************************************************
C ***************************************************************************
C
$INCLUDE: 'COMGRO.DAT'
$INCLUDE: 'COMSOI.DAT'
$INCLUDE: 'COMDIS.DAT'
      COMMON/CCON2/XNCONC
      COMMON/CHUM2/ATPI,ATPS,NRHI,NRHS,NHLRH
      COMMON/CPAT2/CONREM
C
      IF (N .GT. 1) GO TO 100
C
        XNCONC = 0.0
        CONREM = 0.0
        AVG1 = 0.0
        AVG2 = 0.0
        NHH1 = 0
        NHH2 = 0
        SPRE1 = 0.0
        SPRE2 = 0.0
        FPRE1 = 0.0
        FPRE2 = 0.0
        CINDEX = 0.0
C
 100  DISTFA = EXP (-FEX1 * DISTSO / DISTMA)
      CONSUR = EXP (-FEX2 * NHLRH / 8)
C
      AVG3 = AVG2
      AVG2 = AVG1
      AVG1 = ATPS
      AVGT3D = (AVG1 + AVG2 + AVG3) / 3
      NHH3 = NHH2
      NHH2 = NHH1
      NHH1 = NRHS
      ANHH3D = (NHH1 + NHH2 + NHH3) / 3
      SPRE3 = SPRE2
      SPRE2 = SPRE1
      SPRE1 = RAIN
      SAPR3D = (SPRE1 + SPRE2 + SPRE3) / 3 / 10
      FPRE3 = FPRE2
      FPRE2 = FPRE1
      FPRE1 = PRECIP
```

```
      FAPR3D = (FPRE1 + FPRE2 + FPRE3) / 3 / 10
C
      SCOAIR = EXP ((0.2968 * AVGT3D) + (0.1123 * ANHH3D) - (0.942 *
     $    SAPR3D) + 0.5517) / 10000
        IF (SCOAIR .LT. 0.2) SCOAIR = 0.0
        SCOAIR = AMIN1 (SCOAIR, 1.0)
      FCOAIR = EXP ((0.2968 * AVGT3D) + (0.1123 * ANHH3D) - (0.942 *
     $    FAPR3D) + 0.5517) / 10000
        FCOAIR = AMAX1 (0.0, FCOAIR)
        FCOAIR = AMIN1 (FCOAIR, 1.0)
C
      XNCONS = SCOAIR * DENLES
C
      FLIN = XNCONS * DISTFA
      CONPDN = CONREM
      XNCONC = FLIN + CONPDN
      FLOUT = XNCONC * TAKOFF * FCOAIR
      CDECAY = XNCONC * (1 - CONSUR)
      XNCONC = XNCONC - FLOUT - CDECAY
        XNCONC = AMAX1 (0.0, XNCONC)
      CINDEX = XNCONC / 100000.
C
      XINDEX = 0.2477 + (0.1548 * NRHI) - (0.0134 * ATPI) - (0.0036 *
     $    NRHI * ATPI) - (0.0015 * NRHI * NRHI)
        XINDEX = AMAX1 (0.0, XINDEX)
        XINDEX = AMIN1 (XINDEX, 1.0)
        IF (ATPI .LE. 16.0 .OR. NRHI .LT. 3) XINDEX = 0.0
C
      RETURN
      END
```

Filename: IPCERC.FOR

```
$STORAGE: 2
      SUBROUTINE IPCERC
C-------------------------------------------------------------------------
C***  PATHOGEN RACE SELECTION.
C-------------------------------------------------------------------------
$INCLUDE:'COMGRO.DAT'
$INCLUDE:'COMIO.DAT'
$INCLUDE:'COMDIS.DAT'
C-------------------------------------------------------------------------
      II = 0
      OPEN (21,FILE ='CERCIN.DAT',STATUS = 'OLD' )
      IF (NSENS .EQ. 0 ) GO TO 600
      IF (OUTOOP .EQ. 'YES') CALL CLEAR
      IF (OUTOOP .EQ. 'YES') WRITE (*,100)
  100 FORMAT(1X,'PATHOGEN RACE SELECTION.',
     $      /1X,'========================',
     $      /1X,'NO. ','RACE IDENTIFICATION',
     $      /1X,'--- ------------------------ ')
  200 IF (II .LT. 15 .OR. NSENS .EQ. 0) GO TO 500
      IF (OUTOOP .EQ. 'YES') WRITE (*,300)
  300 FORMAT(/,'  More.... PRESS ENTER KEY')
      READ (5,400) ANS
  400 FORMAT(A1)
      II = 0
  500 II = II + 1
  600 READ (21,700,END = 900,ERR = 1800) IRACE,RACEID
      READ (21,*,END = 900,ERR = 1800)   TAKOFF,DISTMA,DENLES,DISTSO
      READ (21,*,END = 900,ERR = 1800)   CONEFF,CPDFAC,AVLEAR
      READ (21,*,END = 900,ERR = 1800)   DFSMAX,DFSMIN,DEFHLT,DEFPRO
      READ (21,*,END = 900,ERR = 1800)   EXPFAC,FACSIT,FRSUSC
      READ (21,*,END = 900,ERR = 1800)   ILAT,XLP1,XLP50,IINF,ZINFEC
        ZINCUB = ILAT / XLP1 * XLP50
        IPRE = IFIX(XLP1) - ILAT
        IF (ILAT .GT. 15 .OR. IPRE .GT. 15) GO TO 1800
        ZMATUR = IPRE / XLP1 * XLP50
      READ (21,*,END = 900,ERR = 1800) COPTT
      READ (21,*,END = 900,ERR = 1800) PFUNGF
      READ (21,*,END = 900,ERR = 1800) PLCA,PLCB,PLCC
      READ (21,*,END = 900,ERR = 1800) DPADJ,RHMINI,RHMINS,RHMAXC
      READ (21,*,END = 900,ERR = 1800) RICHI2,RICHM2,RICHR2
      READ (21,*,END = 900,ERR = 1800) PETFRA,CANHT
      READ (21,*,END = 900,ERR = 1800) FEX1,FEX2,FEX3,FEX4,FLN1
C
      IF (NSENS .EQ. 0 .AND. IRACE .EQ. JDISWT) GO TO 1700
      IF (NSENS .NE. 0 .AND. OUTOOP .EQ. 'YES')  WRITE (*,800)
     $ IRACE,RACEID
  700 FORMAT(1X,I2,1X,A25)
  800 FORMAT(1X,I2,')',1X,A25)
      GO TO 200
  900 IF (NSENS .NE. 0) GO TO 1100
      WRITE (*,1000) JDISWT
```

```
 1000 FORMAT(/,' OOPS! RACE NO ',I3,' NOT FOUND IN FILE : CERCIN.DAT',
     $/T8,'PRESS <Ctrl-Break> KEYS to stop execution and fix the file.')
      READ (5,*) ANS
      GO TO 1700
 1100 REWIND 21
C-------------------------------------------------------------------------
 1200 IF (OUTOOP .EQ. 'YES') WRITE (*,1300) NDISRC,JDISWT
 1300 FORMAT(/1X,I2,']',1X,'<======== PATHOGEN RACE SELECTED',
     $       /1X,I2,']',1X,'<======== CASE STUDY PATHOGEN RACE',/5X,
     $                     '<-------- NEW SELECTION? ')
      READ (5,1400,ERR = 1200) N
 1400 FORMAT(I2)
      IF (N .LT. 0 .OR. N .GT. IRACE) GO TO 1200
      IF (N .NE. 0) NDISRC = N
 1500 READ (21,700,END = 1600,ERR = 1800) IRACE,RACEID
      READ (21,*,END = 1600,ERR = 1800)   TAKOFF,DISTMA,DENLES,DISTSO
      READ (21,*,END = 1600,ERR = 1800)   CONEFF,CPDFAC,AVLEAR
      READ (21,*,END = 1600,ERR = 1800)   DFSMAX,DFSMIN,DEFHLT,DEFPRO
      READ (21,*,END = 1600,ERR = 1800)   EXPFAC,FACSIT,FRSUSC
      READ (21,*,END = 1600,ERR = 1800)   ILAT,XLP1,XLP50,IINF,ZINFEC
        ZINCUB = ILAT / XLP1 * XLP50
        IPRE = IFIX(XLP1) - ILAT
        IF (ILAT .GT. 15 .OR. IPRE .GT. 15) GO TO 1800
        ZMATUR = IPRE / XLP1 * XLP50
      READ (21,*,END = 1600,ERR = 1800) COPTT
      READ (21,*,END = 1600,ERR = 1800) PFUNGF
      READ (21,*,END = 1600,ERR = 1800) PLCA,PLCB,PLCC
      READ (21,*,END = 1600,ERR = 1800) DPADJ,RHMINI,RHMINS,RHMAXC
      READ (21,*,END = 1600,ERR = 1800) RICHI2,RICHM2,RICHR2
      READ (21,*,END = 1600,ERR = 1800) PETFRA,CANHT
      READ (21,*,END = 1600,ERR = 1800) FEX1,FEX2,FEX3,FEX4,FLN1
C
      IF (IRACE .NE. NDISRC) GO TO 1500
      CLOSE (21)
      RETURN
 1600 CONTINUE
      WRITE (*,1000) JDISWT
      READ (5,*) ANS
      CLOSE (21)
      RETURN
 1700 CLOSE (21)
      RETURN
 1800 CONTINUE
      CLOSE (21)
      IF (ILAT .GT. 15 .OR. IPRE .GT. 15) WRITE (*,1850)
      WRITE (*,1900)
 1850 FORMAT(/ ' OOPS! Values of ILAT or XLP1 too high')
 1900 FORMAT(/,' OOPS! Format data miss-match in file : CERCIN.DAT',/T8,
     $'PRESS <Ctrl-Break> KEYS to stop execution and fix the file.')
      READ (5,*) ANS
      STOP
      END
```

Filename: PATHO.FOR

```
$STORAGE:2
$LARGE
C
C ******************************************************************
C ******************************************************************
C ******************************************************************
C
      SUBROUTINE PATHO
C
C ******************************************************************
C ******************************************************************
C ******************************************************************
C
$INCLUDE: 'COMGRO.DAT'
$INCLUDE: 'COMDIS.DAT'
      COMMON/CCON2/XNCONC
      COMMON/CHUM2/ATPI,ATPS,NRHI,NRHS,NHLRH
      COMMON/CPAT2/CONREM
C
      DIMENSION INFSTA(200), SUSLA(200), XNSULS(200), VACSLA(200),
     $    XNVALS(200)
      DIMENSION COLON(15), DEFOL1(15), XLATEN(200,15)
      DIMENSION DEFOL2(15), PREINF(200,15), SPORUL(15)
      DIMENSION DEFOL3(15), POSINF(200), REMOV(15),  XINFLA(200,15)
      DIMENSION TDISLA(200), TINFLA(200), TOTLA(200)
      DIMENSION COHLAR(200), COHLWT(200), COHSLA(200), PHLTIM(200)
C
      IF (N .GT. 1) GO TO 300
C
        ATOTLA = 0.0
        DO 200 I = 1, 200
          TOTLA(I) = 0.0
          TINFLA(I) = 0.0
          TDISLA(I) = 0.0
          DO 100 J = 1, 15
            XLATEN(I,J) = 0.0
            PREINF(I,J) = 0.0
            XINFLA(I,J) = 0.0
 100      CONTINUE
          POSINF(I) = 0.0
          INFSTA(I) = 0
 200    CONTINUE
        CTEMFC = 1.0
        DSEVER = 0.0
        PERDEF = 0.0
        PERDIS = 0.0
        PERINF = 0.0
        WLCDOT = 0.0
        WSCDOT = 0.0
        GDISLA = 0.0
        GINFLA = 0.0
```

```
        GLATLA = 0.0
        GPOSLA = 0.0
        GPRELA = 0.0
        GSPOLA = 0.0
        GTOTLA = 0.0
        TOTLA1 = 0.0
        TOTLA2 = 0.0
        TOTLA3 = 0.0
        TOTLA4 = 0.0
        TOTLA5 = 0.0
        TOTLA6 = 0.0
        TOTLA7 = 0.0
        DEFNAT = 0.0
C
 300  LCOHOR = N - NVEGO + 1
        IF (LCOHOR .LE. 0) RETURN
      COHLWT(LCOHOR) = DWLPOS
      COHSLA(LCOHOR) = F
      COHLAR(LCOHOR) = COHLWT(LCOHOR) * COHSLA(LCOHOR)
      IF (LCOHOR .EQ. 1) PHLTIM(LCOHOR) = DTX
      IF (LCOHOR .GT. 1) PHLTIM(LCOHOR) = PHLTIM(LCOHOR-1) + DTX
      TOTLA(LCOHOR) = COHLAR(LCOHOR)
      SUSLA(LCOHOR) = FRSUSC * TOTLA(LCOHOR)
      WLCDOT = 0.0
      WSCDOT = 0.0
      CONINF = 0.0
      SFREM = 0.0
      ALATLA = 0.0
      APRELA = 0.0
      ASPOLA = 0.0
      APOSLA = 0.0
      ATOTLA = 0.0
C
      CTEMFC = COS (0.1339 * (TAVG - COPTT))
        CTEMFC = AMIN1 (CTEMFC, 1)
        CTEMFC = AMAX1 (0, CTEMFC)
C
      DO 600 LCOH = 1, LCOHOR
          IF (TOTLA(LCOH) .EQ. 0.0) GO TO 600
        VACSLA(LCOH) = SUSLA(LCOH) - TINFLA(LCOH)
        XNVALS(LCOH) = VACSLA(LCOH) * FACSIT * (1. - PFUNGF)
          XNVALS(LCOH) = AMAX1 (0, XNVALS(LCOH))
        XNSULS(LCOH) = SUSLA(LCOH) * FACSIT
C
C ***************************************************************
C
        FOCSLS = (XNSULS(LCOH) - XNVALS(LCOH)) / XNSULS(LCOH)
          FOCSLS = AMAX1 (0.0, FOCSLS)
          FOCSLS = AMIN1 (FOCSLS, 1.0)
        IF (FOCSLS .EQ. 0.0) GMTFAC = 1.0
        IF (FOCSLS .GT. 0.0 .AND. FOCSLS .LT. 1.0) GMTFAC = FLN1 /
     $       (-ALOG (1 - FOCSLS))
        IF (FOCSLS .EQ. 1.0) GMTFAC = 0.0
          GMTFAC = AMIN1 (GMTFAC, 1.0)
```

```
C
      LFRAGE = LCOHOR - LCOH
      PHLAGE = PHLTIM(LCOHOR) - PHLTIM(LCOH)
      RICHB2 = RICHI2 ** (1 - RICHM2) - 1
      PHLAFA = (1 + RICHB2 * EXP (-RICHR2 * PHLAGE)) ** (1 / (1 -
     $     RICHM2))
C
      PROCC = XNCONC * CONEFF * GMTFAC * PHLAFA
C
C ********************************************************************
C
      FLCDIS = TDISLA(LCOH) / TOTLA(LCOH)
      FLCINF = TINFLA(LCOH) / TOTLA(LCOH)
C
      DEFFAC = 0
        IF (FLCINF .GE. DFSMIN .AND. FLCINF .LT. DFSMAX) DEFFAC =
     $     DEFPRO * EXP (-FEX3 * (DFSMAX - FLCINF) / (DFSMAX - DFSMIN))
        IF (FLCINF .GE. DFSMAX) DEFFAC = DEFPRO
      DEFINF = 0.0
C
C ********************************************************************
C ********************************************************************
C ********************************************************************
C
      XINFEC = PROCC * XINDEX / FACSIT * CANHT * (1. - PFUNGF)
      CONINF = CONINF + (PROCC * XINDEX)
        IF (XINFEC .GT. 0.0) INFSTA(LCOH) = 1
        IF (INFSTA(LCOH) .EQ. 0) GO TO 545
      XINEXP = TINFLA(LCOH) * ILAT / ZINCUB * CTEMFC * EXPFAC *
     $      EXP (-FEX4 * FLCINF)
        IF (FLCINF .GE. 1.0) XINEXP = 0.0
      DO 400 I=1,ILAT
        COLON(I) = XLATEN(LCOH,I) * ILAT / ZINCUB * CTEMFC
        DEFADJ = DEFHLT + (1 - DEFHLT) / (ILAT + 1) * I
        DEFOL1(I) = XLATEN(LCOH,I) * DEFFAC * DEFADJ
        DEFINF = DEFINF + DEFOL1(I)
 400    CONTINUE
C
C ********************************************************************
C
      DO 420 I=1,IPRE
        SPORUL(I) = PREINF(LCOH,I) * IPRE / ZMATUR * CTEMFC
        DEFOL2(I) = PREINF(LCOH,I) * DEFFAC
 420    CONTINUE
C
C ********************************************************************
C
      DO 440 I=1,IINF
        REMOV(I) = XINFLA(LCOH,I) * IINF / ZINFEC * FCOAIR
        SFREM = SFREM + REMOV(I)
        DEFOL3(I) = XINFLA(LCOH,I) * DEFFAC
 440    CONTINUE
C
C ********************************************************************
```

```
C
      DEFOL4 = POSINF(LCOH) * DEFFAC
      DEFOLS = AMAX1 (0.0, VACSLA(LCOH)) * DEFFAC * DEFHLT + DEFINF +
     $     TDISLA(LCOH) * DEFFAC
      DEFOLT = AMAX1 (0.0, TOTLA(LCOH) - TINFLA(LCOH)) * DEFFAC *
     $     DEFHLT + DEFINF + TDISLA(LCOH) * DEFFAC
C
C
C ********************************************************************
C ********************************************************************
C ********************************************************************
C
C
      XLATEN(LCOH,1) = XLATEN(LCOH,1) + XINFEC + XINEXP -
     $     COLON(1) - DEFOL1(1)
        XLATEN(LCOH,1) = AMAX1 (0.0, XLATEN(LCOH,1))
      TINFLA(LCOH) = XLATEN(LCOH,1)
      ALATLA = ALATLA + XLATEN(LCOH,1)
      DO 500 I=2,ILAT
        XLATEN(LCOH,I) = XLATEN(LCOH,I) + COLON(I-1) - COLON(I) -
     $       DEFOL1(I)
          XLATEN(LCOH,I) = AMAX1 (0.0, XLATEN(LCOH,I))
        TINFLA(LCOH) = TINFLA(LCOH) + XLATEN(LCOH,I)
        ALATLA = ALATLA + XLATEN(LCOH,I)
 500  CONTINUE
C
C ********************************************************************
C
      PREINF(LCOH,1) = PREINF(LCOH,1) + COLON(ILAT) - SPORUL(1) -
     $     DEFOL2(1)
        PREINF(LCOH,1) = AMAX1 (0.0, PREINF(LCOH,1))
      TINFLA(LCOH) = TINFLA(LCOH) + PREINF(LCOH,1)
      TDISLA(LCOH) = PREINF(LCOH,1)
      APRELA = APRELA + PREINF(LCOH,1)
      DO 520 I=2,IPRE
        PREINF(LCOH,I) = PREINF(LCOH,I) + SPORUL(I-1) - SPORUL(I) -
     $       DEFOL2(I)
          PREINF(LCOH,I) = AMAX1 (0.0, PREINF(LCOH,I))
        TINFLA(LCOH) = TINFLA(LCOH) + PREINF(LCOH,I)
        TDISLA(LCOH) = TDISLA(LCOH) + PREINF(LCOH,I)
        APRELA = APRELA + PREINF(LCOH,I)
 520  CONTINUE
C
C ********************************************************************
C
      XINFLA(LCOH,1) = XINFLA(LCOH,1) + SPORUL(IPRE) - REMOV(1) -
     $     DEFOL3(1)
        XINFLA(LCOH,1) = AMAX1 (0.0, XINFLA(LCOH,1))
      TINFLA(LCOH) = TINFLA(LCOH) + XINFLA(LCOH,1)
      TDISLA(LCOH) = TDISLA(LCOH) + XINFLA(LCOH,1)
      ASPOLA = ASPOLA + XINFLA(LCOH,1)
      DO 540 I=2,IINF
        XINFLA(LCOH,I) = XINFLA(LCOH,I) + REMOV(I-1) - REMOV(I) -
     $       DEFOL3(I)
```

```
          XINFLA(LCOH,I) = AMAX1 (0.0, XINFLA(LCOH,I))
          TINFLA(LCOH) = TINFLA(LCOH) + XINFLA(LCOH,I)
          TDISLA(LCOH) = TDISLA(LCOH) + XINFLA(LCOH,I)
          ASPOLA = ASPOLA + XINFLA(LCOH,I)
 540    CONTINUE
C
C ****************************************************************
C
       POSINF(LCOH) = POSINF(LCOH) + REMOV(IINF) - DEFOL4
         POSINF(LCOH) = AMAX1 (0.0, POSINF(LCOH))
       TINFLA(LCOH) = TINFLA(LCOH) + POSINF(LCOH)
       TDISLA(LCOH) = TDISLA(LCOH) + POSINF(LCOH)
       APOSLA = APOSLA + POSINF(LCOH)
C
C ****************************************************************
C
       SUSLA(LCOH) = SUSLA(LCOH) - DEFOLS
       CCCC = TOTLA(LCOH)
       TOTLA(LCOH) = TOTLA(LCOH) - DEFOLT
         TOTLA(LCOH) = AMAX1 (0.0, TOTLA(LCOH))
       ARLFLS = CCCC - TOTLA(LCOH)
       WTLFLS = ARLFLS / COHSLA(LCOH)
       WTSTLS = PETFRA * WTLFLS
       WLCDOT = WLCDOT + WTLFLS
       WSCDOT = WSCDOT + WTSTLS
 545   ATOTLA = ATOTLA + TOTLA(LCOH)
C
 600  CONTINUE
      CONREM = SFREM * CPDFAC / CANHT
      AINFLA = ALATLA + APRELA + ASPOLA + APOSLA
      ADISLA = APRELA + ASPOLA + APOSLA
C
      GDISLA = ADISLA / 100
      GINFLA = AINFLA / 100
      GLATLA = ALATLA / 100
      GPOSLA = APOSLA
      GPRELA = APRELA / 100
      GSPOLA = ASPOLA
      GTOTLA = ATOTLA / 100
C
      PERINF = 0.0
      PERDIS = 0.0
      IF (ATOTLA .LE. 500.0) GO TO 650
        PERINF = AINFLA / ATOTLA * 100.0
          PERINF = AMIN1 (PERINF, 100.0)
        PERDIS = ADISLA / ATOTLA * 100.0
          PERDIS = AMIN1 (PERDIS, 100.0)
C
 650  DEFOTS = SLDOT + XMLDOT
      IF (ATOTLA .EQ. 0.0) GO TO 850
      DO 840 LCOH=1,LCOHOR
        SSSS = TOTLA(LCOH)
        IF (SSSS .EQ. 0.0) GO TO 840
        TOTLA(LCOH) = TOTLA(LCOH) - (DEFOTS * TOTLA(LCOH) / ATOTLA *
```

```
     $      COHSLA(LCOH))
            TOTLA(LCOH) = AMAX1 (0.0, TOTLA(LCOH))
          SUSLA(LCOH) = SUSLA(LCOH) * TOTLA(LCOH) / SSSS
          TINFLA(LCOH) = TINFLA(LCOH) * TOTLA(LCOH) / SSSS
          TDISLA(LCOH) = TDISLA(LCOH) * TOTLA(LCOH) / SSSS
          DO 810 I=1,ILAT
            XLATEN(LCOH,I) = XLATEN(LCOH,I) * TOTLA(LCOH) / SSSS
 810      CONTINUE
          DO 820 I=1,IPRE
            PREINF(LCOH,I) = PREINF(LCOH,I) * TOTLA(LCOH) / SSSS
 820      CONTINUE
          DO 830 I=1,IINF
            XINFLA(LCOH,I) = XINFLA(LCOH,I) * TOTLA(LCOH) / SSSS
 830      CONTINUE
          POSINF(LCOH) = POSINF(LCOH) * TOTLA(LCOH) / SSSS
 840    CONTINUE
C
 850    TOTLA1 = TOTLA(14)
        TOTLA2 = TOTLA(28)
        TOTLA3 = TOTLA(42)
        TOTLA4 = TOTLA(56)
        TOTLA5 = TOTLA(70)
        TOTLA6 = TOTLA(84)
        TOTLA7 = TOTLA(98)
C
        STOTLA = 0.0
        SCOHLA = 0.0
        DO 900 LCOH = 1, LCOHOR
          STOTLA = STOTLA + TOTLA(LCOH)
          SCOHLA = SCOHLA + COHLAR(LCOH)
 900    CONTINUE
        DEFNAT = DEFNAT + (ATOTLA - STOTLA)
        PERDEF = 0.0
        IF (SCOHLA .GT. 0.0) PERDEF = (SCOHLA - STOTLA - DEFNAT)
     $      / (SCOHLA - DEFNAT ) * 100.
        DSEVER = ((100 - PERDEF) * PERDIS / 100) + PERDEF
C
        RETURN
        END
```

Filename: RHUMID.FOR

```
$STORAGE:2
C
C ******************************************************************
C ******************************************************************
C ******************************************************************
C
      SUBROUTINE RHUMID
C
C ******************************************************************
C ******************************************************************
C ******************************************************************
C
$INCLUDE: 'COMGRO.DAT'
$INCLUDE: 'COMDIS.DAT'
      COMMON/CHUM2/ATPI,ATPS,NRHI,NRHS,NHLRH
      DIMENSION THR2(24),RH(24)
C
      IF (N .GT. 1) GO TO 60
C
        PI = 3.141593
        DYLEN = SNDNY - SNUPY
        HTMIN = SNUPY + PLCC
        TAU1 = PI * (SNDNY - HTMIN) / (DYLEN + 2 * PLCA)
        TSET = TMINY + (TMAXY - TMINY) * SIN (TAU1)
        TMINP = TMINY
        NHHRHS = 0
        SMTEMS = 0
        NHHRHI = 0
        SMTEMI = 0
        DO 50 IXX = 1, 24
          THR2(IXX) = 0.0
          RH(IXX) = 0.0
 50     CONTINUE
C
 60   NHLRH = 0
      TSETY = TSET
      DYLEN = SNDN - SNUP
      HTMIN = SNUP + PLCC
      TAU1 = PI * (SNDN - HTMIN) / (DYLEN + 2 * PLCA)
      TSET = TMIN + (TMAX - TMIN) * SIN (TAU1)
      DEPLFM = (TSETY - TMIN) / (EXP (PLCB) - 1)
      DEPLFE = (TSET - TMINT) / (EXP (PLCB) - 1)
C
      DO 100 IXX = 1, 24
        IF (IXX .LE. HTMIN) THEN
          TAU2 = -PLCB * (24 + IXX - SNDN) / (24 - DYLEN + PLCC)
          THR2(IXX) = (TMIN - DEPLFM) + (TSETY - (TMIN - DEPLFM)) *
     $          EXP (TAU2)
        ELSE
          IF (IXX .LE. SNDN) THEN
            TAU3 = PI * (IXX - HTMIN) / (DYLEN + 2 * PLCA)
```

```
            THR2(IXX) = TMIN + (TMAX - TMIN) * SIN (TAU3)
          ELSE
            TAU4 = -PLCB * (IXX - SNDN) / (24 - DYLEN + PLCC)
            THR2(IXX) = (TMINT - DEPLFE) + (TSET - (TMINT - DEPLFE)) *
     $          EXP (TAU4)
          ENDIF
        ENDIF
C
        IF (IXX .GE. HTMIN) TMINP = TMIN
        DPTEMP = TMINP + DPADJ
        AVAPP = .61078 * EXP (17.2693882 * DPTEMP / (237.3 + DPTEMP))
        SVAPP = .61078 * EXP (17.2693882 * THR2(IXX)/(237.3 +
     $       THR2(IXX)))
        RH(IXX) = AVAPP / SVAPP * 100.
          RH(IXX) = AMIN1 (RH(IXX), 100.0)
C
C ****************************************************************
C
        IF (RH(IXX) .GE. RHMINS) THEN
          NHHRHS = NHHRHS + 1
          SMTEMS = SMTEMS + THR2(IXX)
        ELSE
          IF (NHHRHS .EQ. 0) GO TO 70
          NRHS = NHHRHS
          STPS = SMTEMS
          NHHRHS = 0
          SMTEMS = 0.0
 70     ENDIF
C
        IF (RH(IXX) .GE. RHMINI) THEN
          NHHRHI = NHHRHI + 1
          SMTEMI = SMTEMI + THR2(IXX)
        ELSE
          IF (NHHRHI .EQ. 0) GO TO 80
          NRHI = NHHRHI
          STPI = SMTEMI
          NHHRHI = 0
          SMTEMI = 0.0
 80     ENDIF
C
        IF (RH(IXX) .LE. RHMAXC) NHLRH = NHLRH + 1
C
C ****************************************************************
C
 100  CONTINUE
C
      ATPS = 0.0
      IF (NRHS .GT. 0) ATPS = STPS / NRHS
      ATPI = 0.0
      IF (NRHI .GT. 0) ATPI = STPI / NRHI
C
      RETURN
      END
```

Filename: CERCIN.DAT

```
  1 Good Disease Ctrl (GDC)          *** IRACE,RACEID ***
0.25  10000.0  100.0   1000.        TAKOFF, DISTMA, DENLES, DISTSO
0.85  25000.  0.001                 CONEFF, CPDFAC, AVLEAR
0.75  0.30  0.68  1.00              DFSMAX, DFSMIN, DEFHLT, DEFPRO
1.10  40000.  0.50                  EXPFAC, FACSIT, FRSUSC
10  19  25   2   5                  ILAT, XLP1, XLP50, IINF, ZINFEC
24                                  COPTT
1.00                                PFUNGF
1.86  2.20  1.50                    PLCA, PLCB, PLCC
0.00  93.0  90.0  40.0              DPADJ, RHMINI, RHMINS, RHMAXC
0.0001  2.00  1.32                  RICHI2, RICHM2, RICHR2
0.21  0.40                          PETFRA, CANHT
3  3  4  5  0.01                    FEX1, FEX2, FEX3, FEX4, FLN1

  2 No Dis. Ctrl (I.S.=far)         *** IRACE,RACEID ***
0.25  10000.0  100.0   1000.        TAKOFF, DISTMA, DENLES, DISTSO
0.85  25000.  0.001                 CONEFF, CPDFAC, AVLEAR
0.75  0.30  0.68  1.00              DFSMAX, DFSMIN, DEFHLT, DEFPRO
1.10  40000.  0.50                  EXPFAC, FACSIT, FRSUSC
10  19  25   2   5                  ILAT, XLP1, XLP50, IINF, ZINFEC
24                                  COPTT
0.00                                PFUNGF
1.86  2.20  1.50                    PLCA, PLCB, PLCC
0.00  93.0  90.0  40.0              DPADJ, RHMINI, RHMINS, RHMAXC
0.0001  2.00  1.32                  RICHI2, RICHM2, RICHR2
0.21  0.40                          PETFRA, CANHT
3  3  4  5  0.01                    FEX1, FEX2, FEX3, FEX4, FLN1

  3 No Dis. Ctrl (I.S.=close)       *** IRACE,RACEID ***
0.25  10000.0  100.0   10.0        TAKOFF, DISTMA, DENLES, DISTSO
0.85  25000.  0.001                 CONEFF, CPDFAC, AVLEAR
0.75  0.30  0.68  1.00              DFSMAX, DFSMIN, DEFHLT, DEFPRO
1.10  40000.  0.50                  EXPFAC, FACSIT, FRSUSC
10  19  25   2   5                  ILAT, XLP1, XLP50, IINF, ZINFEC
24                                  COPTT
0.00                                PFUNGF
1.86  2.20  1.50                    PLCA, PLCB, PLCC
0.00  93.0  90.0  40.0              DPADJ, RHMINI, RHMINS, RHMAXC
0.0001  2.00  1.32                  RICHI2, RICHM2, RICHR2
0.21  0.40                          PETFRA, CANHT
3  3  5  5  0.01                    FEX1, FEX2, FEX3; FEX4, FLN1
```

APPENDIX E

DEFINITION OF VARIABLES USED IN THE MODEL

The variables in this list are described as follows:

NAME [TYPE, LINKAGE (if local variable) or /COMMON STATEMENT NAME/, SUBROUTINE(S) in which it is used, SUBROUTINE CODE] - Definition of variable, (units).

The following codes appear after the variable names in the glossary:

CODE	VARIABLE TYPE
A	ASCII
I	INTEGER
R	REAL
R(i)	REAL (one-dimensional array)
R(i,j)	REAL (two-dimensional array)

The following codes appear after the subroutine names in the glossary:

CODE	SUBROUTINE CODE
M	Variable is modified in one or more assignment statements of this function or subroutine.
S	Variable is in a DATA-mode specification of this function or subroutine.

GLOSSARY

ADISLA [R, LINKAGE, PATHO M S] - Total diseased leaf area of all leaf cohorts; Symptoms of the disease are visible as necrotic lesions in the pre-infectious, infectious, or post-infectious states ($cm^2\ m^{-2}$).

AINFLA [R, LINKAGE, PATHO M S] - Total infected leaf area of all leaf cohorts; All leaf area where the pathogen is present ($cm^2\ m^{-2}$).

ALATLA [R, LINKAGE, PATHO M S] - Total latently infected leaf area of all leaf cohorts; The pathogen is present in the leaf but does not show any symptoms ($cm^2\ m^{-2}$).

ALOG( ) FORTRAN function: Natural logarithm of the argument in parentheses.

AMAX1( ) FORTRAN function: Maximum value of arguments in parentheses.

AMIN1( ) FORTRAN function: Minimum value of arguments in parentheses.

ANHH3D [R, LINKAGE, CONIDI M S] - Average number of successive hours of relative humidity over the minimum relative humidity for sporulation, RHMINS during the last three days ($h\ d^{-1}$).

APOSLA [R, LINKAGE, PATHO M S] - Total post-infectious leaf area of all leaf cohorts; Necrotic leaf area that has completed the sporulation process ($cm^2\ m^{-2}$).

APRELA [R, LINKAGE, PATHO M S] - Total pre-infectious leaf area of all leaf cohorts; Leaf area showing symptoms of the disease (necrotic area) but not sporulating yet ($cm^2\ m^{-2}$).

ARLFLS [R, LINKAGE, PATHO M S] - Leaf area of all leaf cohorts lost due to disease-induced defoliation ($cm^2\ m^{-2}$).

ASPOLA [R, LINKAGE, PATHO M S] - Total sporulating (infectious) leaf area of all leaf cohorts ($cm^2\ m^{-2}$).

ATOTLA [R, LINKAGE, PATHO M S] - Total leaf area of all leaf cohorts ($cm^2\ m^{-2}$).

ATPI [R, /CHUM2/, CONIDI S: RHUMID M] - Average temperature for infection during period of relative humidity over the minimum relative humidity for infection, RHMINI (°C).

ATPS [R, /CHUM2/, CONIDI S: RHUMID M] - Average temperature for spore release during period of relative humidity over the minimum relative humidity for spore release, RHMINS (°C).

AVAPP [R, LINKAGE, RHUMID M S] - Actual vapor pressure of the air; Based on the dew point temperature (kPa).

AVG1 [R, LINKAGE, CONIDI M S] - Average temperature for spore release (ATPS) of the actual day (°C).

AVG2 [R, LINKAGE, CONIDI M S] - Average temperature for spore release (ATPS) of the previous day (°C).

AVG3 [R, LINKAGE, CONIDI M S] - Average temperature for spore release (ATPS) of two days ago (°C).

AVGT3D [R, LINKAGE, CONIDI M S] - Average temperature for spore release (ATPS) during the last three days (°C).

AVLEAR [R, /CCON1/, IPCERC M] - Average area of a necrotic lesion; Not used in the model (cm^2).

CANHT [R, /CPAT1/, IPCERC M: PATHO S] - Canopy height (m).

CCCC [R, LINKAGE, PATHO M S] - Auxilliary variable used in the computation of the total leaf area lost due to disease-induced defoliation, ARLFLS ($cm^2\ m^{-2}$).

CDECAY [R, LINKAGE, CONIDI M S] - Decay rate of leafspot conidia (# conidia $cm^{-3}\ d^{-1}$).

CINDEX [R, /CCOUT/, CONIDI M: OPSEAS S] - Number of conidia at the field site under study, XNCONC; Variable used in the graphics routine (# conidia $m^{-3} * 10^5$).

COHLAR [R(i), LINKAGE, PATHO M S] - Leaf area of leaf cohort i ($cm^2\ m^{-2}$).

COHLWT [R(i), LINKAGE, PATHO M S] - Leaf dry weight of leaf cohort i ($g\ m^{-2}$).

COHSLA [R(i), LINKAGE, PATHO M S] - Specific leaf area of leaf cohort i ($cm^2\ g^{-1}$).

COLON [R(i), LINKAGE, PATHO M S] - Colonization rate of the pathogen in the latently infected leaf area state i ($cm^2\ m^{-2}\ d^{-1}$).

CONEFF [R, /CPAT1/, IPCERC M: PATHO S] - Conidia infection efficiency under optimal conditions; Number of conidia which infect the leaf per number of conidia inoculated.

CONINF [R, LINKAGE, PATHO M S] - Number of conidia infecting the leaves of all leaf cohorts (# conidia $m^{-3}\ d^{-1}$).

CONPDN [R, LINKAGE, CONIDI M S] - Number of conidia released by the sporulating leaf area of all leaf cohorts (# conidia $m^{-3}\ d^{-1}$).

CONREM [R, /CPAT2/, CONIDI M S: PATHO M] - Number of conidia removed from the sporulating leaf area of all leaf cohorts (# conidia $m^{-3}\ d^{-1}$).

CONSUR [R, LINKAGE, CONIDI M S] - Fraction of conidia that will survive a period of relative humidity below a maximum relative humidity for survival of the conidia (RHMAXC).

COPTT [R, /CPAT1/, IPCERC M: PATHO S] - Optimum temperature for pathogen development in the leaf (°C).

CPDFAC [R, /CPAT1/, IPCERC M: PATHO S] - Number of conidia produced by unit area of a sporulating lesion (# conidia cm^{-2}).

CTEMFC [R, /CCOUT/, OPSEAS S: PATHO M S] - Temperature factor for pathogen development in the leaf.

DEFADJ [R, LINKAGE, PATHO M S] - Disease-induced defoliation factor adjusting for latently infected leaf area; Latently infected leaf area does not defoliate as fast as later stages of pathogen development.

DEFFAC [R, LINKAGE, PATHO M S] - General disease-induced defoliation factor.

DEFHLT [R, /CPAT1/, IPCERC M: PATHO S] - Disease-induced defoliation factor of healthy leaf tissue.

DEFINF [R, LINKAGE, PATHO M S] - Disease-induced defoliation rate of latently infected leaf area within a leaf cohort ($cm^2\ m^{-2}\ d^{-1}$).

DEFNAT [R, LINKAGE, PATHO M S] - Cumulative leaf area that is lost due to natural defoliation ($cm^2\ m^{-2}$).

DEFOL1 [R(i), LINKAGE, PATHO M S] - Disease-induced defoliation rate of latently infected leaf area in state i within a leaf cohort ($cm^2\ m^{-2}\ d^{-1}$).

DEFOL2 [R(i), LINKAGE, PATHO M S] - Disease-induced defoliation rate of pre-infectious leaf area in state i within a leaf cohort ($cm^2\ m^{-2}\ d^{-1}$).

DEFOL3 [R(i), LINKAGE, PATHO M S] - Disease-induced defoliation rate of infectious leaf area in state i within a leaf cohort ($cm^2\ m^{-2}\ d^{-1}$).

DEFOL4 [R, LINKAGE, PATHO M S] - Disease-induced defoliation rate of post-infectious leaf area in state i within a leaf cohort ($cm^2\ m^{-2}\ d^{-1}$).

DEFOLS [R, LINKAGE, PATHO M S] - Disease-induced defoliation rate of susceptible leaf area within a leaf cohort ($cm^2\ m^{-2}\ d^{-1}$).

DEFOLT [R, LINKAGE, PATHO M S] - Disease-induced defoliation rate of total leaf area within a leaf cohort ($cm^2\ m^{-2}\ d^{-1}$).

DEFOTS [R, LINKAGE, PATHO M S] - Loss of leaf dry weight due to natural senescence and water stress ($g\ m^{-2}\ d^{-1}$).

DEFPRO [R, /CPAT1/, IPCERC M: PATHO S] - Maximum disease-induced defoliation factor that can occur in one day.

DENLES [R, /CCON1/, CONIDI S: IPCERC M] - Maximum number of conidia that can be disseminated from the site of inoculum source (# conidia $m^{-3}\ d^{-1}$).

DEPLFE [R, LINKAGE, RHUMID M S] - Displacement factor for the evening in the equation computing the hourly air temperatures from daily maximum and minimum temperatures (°C).

DEPLFM [R, LINKAGE, RHUMID M S] - Displacement factor for the morning in the equation computing the hourly air temperatures from daily maximum and minimum temperatures (°C).

DFSMAX [R, /CPAT1/, IPCERC M: PATHO S] - Infected leaf area proportion at which maximum disease-induced defoliation occurs.

DFSMIN [R, /CPAT1/, IPCERC M: PATHO S] - Infected leaf area proportion at which minimum disease-induced defoliation occurs; No disease-induced defoliation occurs below this value.

DISTFA [R, LINKAGE, CONIDI M S] - Distance factor for conidia dissemination.

DISTMA [R, /CCON1/, CONIDI S: IPCERC M] - Maximum distance conidia can travel for the infection of leaflets (m).

DISTSO [R, /CCON1/, CONIDI S: IPCERC M] - Distance of the field site under study from the site of inoculum source (m).

DPADJ [R, /CHUM1/, IPCERC M: RHUMID S] - Dew point temperature adjustment in relation to the minimum temperature (°C).

DPTEMP [R, LINKAGE, RHUMID M S] - Dew point temperature (°C).

DSEVER [R, /CCOUT/, PATHO M] - Canopy disease severity (%).

DTX [R, /PHEN3/, PATHO S: other PNUTGRO sub.] - Number of physiological days accumulated in one day (d).

DWLPOS [R, /CCRO1/, CROP M S: PATHO S] - Dry weight of leaves produced in one day ($g\ m^{-2}\ d^{-1}$).

DYLEN [R, LINKAGE, RHUMID M S] - Astronomical daylength (h).

EXP( ) FORTRAN function: Natural exponential of the argument in parentheses.

EXPFAC [R, /CPAT1/, IPCERC M: PATHO S] - Expansion factor of the infected leaf area.

F [R, /PLANT6/, PATHO S: other PNUTGRO sub.] - Ratio of leaf area to leaf weight for leaf tissue which is added on a given day ($cm^2\ g^{-1}$).

FACSIT [R, /CPAT1/, IPCERC M: PATHO S] - Number of leaf sites per unit of leaf area; One leaf site is the area affected by one conidia of the pathogen (# sites cm^{-2}).

FAPR3D [R, LINKAGE, CONIDI M S] - Average precipitation (rain and irrigation) for spore release at the field site under study during the last three days ($cm\ d^{-1}$).

FCOAIR [R, /CCOUT/, CONIDI M S: OPSEAS S: PATHO S] - Factor expressing the favorability of the environment for spore release at the field site under study.

FEX1 [R, /CCON1/, CONIDI S: IPCERC M] - Constant in the exponential function used to compute DISTFA.

FEX2 [R, /CCON1/, CONIDI S: IPCERC M] - Constant in the exponential function used to compute CONSUR.

FEX3 [R, /CPAT1/, IPCERC M: PATHO S] - Constant in the exponential function used to compute DEFFAC.

FEX4 [R, /CPAT1/, IPCERC M: PATHO S] - Constant in the exponential function used to compute XINEXP.

FLCDIS [R, LINKAGE, PATHO M S] - Fraction of diseased leaf area in a leaf cohort.

FLCINF [R, LINKAGE, PATHO M S] - Fraction of infected leaf area in a leaf cohort.

FLIN [R, LINKAGE, CONIDI M S] - Number of conidia flying in the field site under study from the site of inoculum source (# conidia m^{-3} d^{-1}).

FLN1 [R, /CPAT1/, IPCERC M: PATHO S] - Constant in the function used to compute GMTFAC.

FLOUT [R, LINKAGE, CONIDI M S] - Number of conidia flying out of the field site under study (# conidia m^{-3} d^{-1}).

FOCSLS [R, LINKAGE, PATHO M S] - Fraction of susceptible leaf sites that are occupied by the pathogen in a leaf cohort.

FPRE1 [R, LINKAGE, CONIDI M S] - Average precipitation (rain and irrigation) for spore release of the actual day at the field site under study (mm d^{-1}).

FPRE2 [R, LINKAGE, CONIDI M S] - Average precipitation (rain and irrigation) for spore release of the previous day at the field site under study (mm d^{-1}).

FPRE3 [R, LINKAGE, CONIDI M S] - Average precipitation (rain and irrigation) for spore release of two days ago at the field site under study (mm d^{-1}).

FRSUSC [R, /CPAT1/, IPCERC M: PATHO S] - Fraction of the total leaf area that is susceptible to infection by the pathogen.

GDISLA [R, /CCOUT/, OPSEAS S: PATHO M] - Variable ADISLA transformed for graphics routine (dm^2 m^{-2}).

GINFLA [R, /CCOUT/, OPSEAS S: PATHO M] - Variable AINFLA transformed for graphics routine ($dm^2\ m^{-2}$).

GMTFAC [R, LINKAGE, PATHO M S] - Gregory multiple transformation factor used in the determination of infection by the pathogen.

GLATLA [R, /CCOUT/, OPSEAS S: PATHO M] - Variable ALATLA transformed for graphics routine ($dm^2\ m^{-2}$).

GPOSLA [R, /CCOUT/, OPSEAS S: PATHO M] - Variable APOSLA transformed for graphics routine ($cm^2\ m^{-2}$).

GPRELA [R, /CCOUT/, OPSEAS S: PATHO M] - Variable APRELA transformed for graphics routine ($dm^2\ m^{-2}$).

GSPOLA [R, /CCOUT/, OPSEAS S: PATHO M] - Variable ASPOLA transformed for graphics routine ($cm^2\ m^{-2}$).

GTOTLA [R, /CCOUT/, OPSEAS S: PATHO M] - Variable ATOTLA transformed for graphics routine ($dm^2\ m^{-2}$).

HTMIN [R, LINKAGE, RHUMID M S] - Time when the minimum temperature occurs during the day (h).

IFIX FORTRAN function: Integer value of argument in parentheses.

IINF [I, /CPAT1/, IPCERC M: PATHO S] - Time from beginning of sporulation to first lesions releasing their spores; infectious period 1 (d) -- ($IINF \leq 15$).

ILAT [I, /CPAT1/, IPCERC M S: PATHO S] - Time from exposure or inoculation of the pathogen to first observation of symptoms (necrotic area); incubation period 1 (d) -- ($ILAT \leq 15$).

INFSTA [R(i), LINKAGE, PATHO M S] - Infection status switch used to save computer time; 0 - leaf was not infected, 1 - leaf was infected.

IPRE [I, /CPAT1/, IPCERC M S: PATHO S] - Time from first observation of symptoms (necrotic area) to first lesion showing sporulation; maturation period 1 (d).

IRACE [I, LINKAGE, IPCERC M S] - Flag number of a fictive pathogen race used in the sensitivity analyses within PNUTGRO.

IXX [I, LINKAGE, RHUMID M S] - Time of the day (h).

JDISWT [I, /CCRO1/, GRO M S: IPCERC S: IPEXP M S] - Flag number of a fictive pathogen race in the file PN8 (treatment initialization) of PNUTGRO.

LCOH [I, LINKAGE, PATHO M S] - Leaf cohort number used in daily loop.

LCOHOR [I, LINKAGE, PATHO M S] - Leaf cohort number of the last leaf cohort created.

LFRAGE [I, LINKAGE, PATHO M] - Leaf real age (d).

N [I, /FIELD1/, CONIDI S: IPCERC S: PATHO S: RHUMID S: other PNUTGRO sub.] - Day counter; Begins on day user wishes to start keeping track of soil water content.

NDISRC [I, /CCRO1/, GRO M S: IPCERC M S: IPEXP M: IPSENS S] - Flag number of a fictive pathogen race used in the sensitivity analyses within PNUTGRO.

NHH1 [I, LINKAGE, CONIDI M S] - Number of successive hours of relative humidity over the minimum relative humidity for spore release, RHMINS, during the actual day (h d^{-1}).

NHH2 [I, LINKAGE, CONIDI M S] - Number of successive hours of relative humidity over the minimum relative humidity for spore release, RHMINS, during the previous day (h d^{-1}).

NHH3 [I, LINKAGE, CONIDI M S] - Number of successive hours of relative humidity over the minimum relative humidity for spore release, RHMINS, two days ago (h d^{-1}).

NHHRHI [I, LINKAGE, RHUMID M S] - Number of successive hours of relative humidity over the minimum relative humidity for infection, RHMINI, during the actual day (h d^{-1}).

NHHRHS [I, LINKAGE, RHUMID M S] - Number of successive hours of relative humidity over the minimum relative humidity for spore release, RHMINS, during the actual day (h d^{-1}).

NHLRH [I, /CHUM2/, CONIDI S: RHUMID M S] - Number of successive hours of relative humidity below the maximum relative humidity for conidia survival, RHMAXC, during the actual day (h d^{-1}).

NRHI [I, /CHUM2/, CONIDI S: RHUMID M S] - Number of successive hours of relative humidity over the minimum relative humidity for infection, RHMINI, during the actual day (h d^{-1}).

NRHS [I, /CHUM2/, CONIDI S: RHUMID M S] - Number of successive hours of relative humidity over the minimum relative humidity for spore release, RHMINS, during the actual day (h d^{-1}).

NSENS [I, /DATA1/, IPCERC S: other PNUTGRO sub.] - Option number: 0 - run simulation, 1 - select variables for sensitivity analysis, 2 - select simulation output frequency.

NVEGO [I, /PHEN1/, PATHO S: other PNUTGRO sub.] - Number of days from planting until emergence (d).

OUTOOP [A, /FILES4/, IPCERC S: other PNUTGRO sub.] - Yes of no flag that calls for output to the screen.

PERDEF [R, /CCOUT/, OPSEAS S: PATHO M S] - Percentage of leaf area defoliated in the canopy (%).

PERDIS [R, /CCOUT/, CROP S: OPSEAS S: PATHO M S] - Percentage of diseased leaf area in the canopy (%).

PERINF [R, /CCOUT/, OPSEAS S: PATHO M] - Percentage of infected leaf area in the canopy (%).

PETFRA [R, /CPAT1/, IPCERC M: PATHO S] - Proportion of petiole dry weight in the leaf.

PFUNGF [R, /CCRO1/, IPCERC M: PATHO S] - Protectant fungicide factor used to create the presence (0) or absence (1) of the disease; This factor may be considered as the fungicide effectiveness but there are no true fungicide application subroutines included in the model.

PHLAFA [R, LINKAGE, PATHO M S] - Factor of the physiological age of the leaf used to determine when the leaf becomes susceptible to the pathogen.

PHLAGE [R, LINKAGE, PATHO M S] - Leaf physiological age (d).

PHLTIM [R(i), LINKAGE, PATHO M S] - Crop physiological time when leaf cohort i appears (d).

PI [R, LINKAGE, RHUMID M S] - Constant π = 3.141593.

PLCA [R, /CHUM1/, IPCERC M: RHUMID S] - Parton and Logan (1981) constant a; Time lag in maximum temperature after noon (h).

PLCB [R, /CHUM1/, IPCERC M: RHUMID S] - Parton and Logan (1981) constant b; Coefficient that controls temperature decrease at night.

PLCC [R, /CHUM1/, IPCERC M: RHUMID S] - Parton and Logan (1981) constant c; Time lag for the minimum temperature after sunrise (h).

POSINF [R(i), LINKAGE, PATHO M S] - Post-infectious leaf area in leaf cohort i ($cm^2\ m^{-2}$).

PRECIP [R, /WATER/, CONIDI S: other PNUTGRO sub.] - Amount of daily precipitations in the form of rain or irrigation ($mm\ d^{-1}$).

PREINF [R(i,j), LINKAGE, PATHO M S] - Pre-infectious leaf area in state j in leaf cohort i ($cm^2\ m^{-2}$).

PROCC [R, LINKAGE, PATHO M S] - Number of conidia that will occupy susceptible leaf sites that are vacant under optimal environmental conditions (# conidia m^{-3}).

RACEID [A, /CCRO1/, IPCERC M S: IPEXP M: IPSENS S] - Name of a fictive pathogen race used in sensitivity analyses within PNUTGRO.

RAIN [R, /ENVIR2/, CONIDI S: other PNUTGRO sub.] - Amount of daily rainfall (mm d^{-1}).

REMOV [R(i), LINKAGE, PATHO M S] - Removal rate of infectious leaf area in state i due to spore release (cm^2 m^{-2} d^{-1}).

RH [R(i), LINKAGE, RHUMID M S] - Relative humidity at time i during the day (%).

RHMAXC [R, /CHUM1/, IPCERC M: RHUMID S] - Maximum relative humidity for conidia survival; lower values than RHMAXC will produce stress on the conidia (%).

RHMINI [R, /CHUM1/, IPCERC M: RHUMID S] - Minimum relative humidity for pathogen infection; higher values than RHMINI will favor infection by the pathogen (%).

RHMINS [R, /CHUM1/, IPCERC M: RHUMID S] - Minimum relative humidity for spore release; higher values than RHMINS will favor conditions leading to spore release when the leaf is dry (%).

RICHB2 [R, LINKAGE, PATHO M S] - Parameter B in Richards equation; Constant of integration.

RICHI2 [R, /CPAT1/, IPCERC M: PATHO S] - Parameter y_0 in Richards equation; Initial value.

RICHM2 [R, /CPAT1/, IPCERC M: PATHO S] - Parameter m in Richards equation; Determines shape of the curve.

RICHR2 [R, /CPAT1/, IPCERC M: PATHO S] - Parameter r in Richards equation; Rate of progress.

SAPR3D [R, LINKAGE, CONIDI M S] - Average rainfall for spore release at the site of inoculum source during the last three days (cm d^{-1}).

SCOAIR [R, /CCOUT/, CONIDI M S: OPSEAS S] - Factor expressing the favorability of the environment for spore release at the site of inoculum source.

SCOHLA [R, LINKAGE, PATHO M S] - Total leaf area of all leaf cohorts produced during the growing season; This value is not affected by any leaf losses (cm^2 m^{-2}).

SFREM [R, LINKAGE, PATHO M S] - Infectious leaf area of all leaf cohorts that is removed due to spore release (cm^2 m^{-2}).

SIN( ) FORTRAN function: Sine of the argument in the parentheses.

SLDOT [R, /PLANT4/, PATHO M S: other PNUTGRO sub.] - Daily senescence of leaves (g m^{-2} d^{-1}).

SMTEMI [R, LINKAGE, RHUMID M S] - Cumulative temperature during successive hours of relative humidity over the minimum relative humidity for infection, RHMINI, during the actual day (°C).

SMTEMS [R, LINKAGE, RHUMID M S] - Cumulative temperature during successive hours of relative humidity over the minimum relative humidity for spore release, RHMINS, during the actual day (°C).

SNDN [R, /ENVIR1/, RHUMID S: other PNUTGRO sub.] - Hour of sunset each day (h).

SNDNY [R, /ENVIR2/, RHUMID S: other PNUTGRO sub.] - Hour of sunset yesterday (h).

SNUP [R, /ENVIR1/, RHUMID S: other PNUTGRO sub.] - Hour of sunrise each day (h).

SNUPY [R, /ENVIR2/, RHUMID S: other PNUTGRO sub.] - Hour of sunrise yesterday (h).

SPORUL [R(i), LINKAGE, PATHO M S] - Sporulation rate of the pre-infectious leaf area in state i (cm^2 m^{-2} d^{-1}).

SPRE1 [R, LINKAGE, CONIDI M S] - Average rainfall for spore release of the actual day at the site of inoculum source (mm d^{-1}).

SPRE2 [R, LINKAGE, CONIDI M S] - Average rainfall for spore release of the previous day at the site of inoculum source (mm d^{-1}).

SPRE3 [R, LINKAGE, CONIDI M S] - Average rainfall for spore release of two days ago at the site of inoculum source (mm d^{-1}).

SSSS [R, LINKAGE, PATHO M S] - Auxilliary variable used in the computation of the total leaf area lost due to natural defoliation (cm^2 m^{-2}).

STOTLA [R, LINKAGE, PATHO M S] - Total leaf area of all leaf cohorts after diseased-induced defoliation (cm^2 m^{-2}).

STPI [R, LINKAGE, RHUMID M S] - Cumulative temperature during successive hours of relative humidity over the minimum relative humidity for infection, RHMINI, during the actual day (°C).

STPS [R, LINKAGE, RHUMID M S] - Cumulative temperature during successive hours of relative humidity over the minimum relative humidity for spore release, RHMINS, during the actual day (°C).

SUSLA [R(i), LINKAGE, PATHO M S] - Susceptible leaf area of leaf cohort i (cm^2 m^{-2})

SVAPP [R, LINKAGE, RHUMID M S] - Saturated vapor pressure at the dry bulb temperature (kPa).

TAKOFF [R, /CCON1/, CONIDI S: IPCERC M] - Fraction of spores taking off from the field site under optimal environmental conditions.

TAU1 [R, LINKAGE, RHUMID M S] - Auxilliary variable used to compute TSET.

TAU2 [R, LINKAGE, RHUMID M S] - Auxilliary variable used to compute THR2 between midnight and HTMIN.

TAU3 [R, LINKAGE, RHUMID M S] - Auxilliary variable used to compute THR2 between HTMIN and SNDN.

TAU4 [R, LINKAGE, RHUMID M S] - Auxilliary variable used to compute THR2 between SNDN and midnight.

TAVG [R, /ENVIR1/, PATHO S: other PNUTGRO sub.] - Average of the 24 hourly temperatures estimated each day (°C).

TDISLA [R(i), LINKAGE, PATHO M S] - Total diseased leaf area of leaf cohort i ($cm^2\ m^{-2}$).

THR2 [R(i), LINKAGE, RHUMID M S] - Air temperature at time i (°C).

TINFLA [R(i), LINKAGE, PATHO M S] - Total infected leaf area of leaf cohort i ($cm^2\ m^{-2}$).

TMAX [R, /ENVIR1/, RHUMID S: other PNUTGRO sub.] - Daily maximum temperature (°C).

TMAXY [R, /ENVIR1/, RHUMID S: other PNUTGRO sub.] - Maximum temperature of yesterday (°C).

TMIN [R, /ENVIR1/, RHUMID S: other PNUTGRO sub.] - Daily minimum temperature (°C).

TMINP [R, LINKAGE, RHUMID M S] - Minimum temperature of the previous day (°C).

TMINT [R, /ENVIR1/, RHUMID S: other PNUTGRO sub.] - Minimum temperature of tomorrow (°C).

TMINY [R, /ENVIR1/, RHUMID S: other PNUTGRO sub.] - Minimum temperature of yesterday (°C).

TOTLA [R(i), LINKAGE, PATHO M S] - Total leaf area of leaf cohort i ($cm^2\ m^{-2}$).

TOTLA1 [R, /CCOUT/, OPSEAS S: PATHO M] - Total leaf area of leaf cohort i=14 ($cm^2\ m^{-2}$).

TOTLA2 [R, /CCOUT/, OPSEAS S: PATHO M] - Total leaf area of leaf cohort i=28 ($cm^2\ m^{-2}$).

TOTLA3 [R, /CCOUT/, OPSEAS S: PATHO M] - Total leaf area of leaf cohort i=42 ($cm^2\ m^{-2}$).

TOTLA4 [R, /CCOUT/, OPSEAS S: PATHO M] - Total leaf area of leaf cohort i=56 ($cm^2\ m^{-2}$).

TOTLA5 [R, /CCOUT/, OPSEAS S: PATHO M] - Total leaf area of leaf cohort i=70 ($cm^2\ m^{-2}$).

TOTLA6 [R, /CCOUT/, OPSEAS S: PATHO M] - Total leaf area of leaf cohort i=84 ($cm^2\ m^{-2}$).

TOTLA7 [R, /CCOUT/, OPSEAS S: PATHO M] - Total leaf area of leaf cohort i=98 ($cm^2\ m^{-2}$).

TSET [R, LINKAGE, RHUMID M S] - Air temperature at sunset (°C).

TSETY [R, LINKAGE, RHUMID M S] - Air temperature at sunset of yesterday (°C).

VACSLA [R(i), LINKAGE, PATHO M S] - Susceptible leaf area that is vacant in leaf cohort i ($cm^2\ m^{-2}$).

WLCDOT [R, /CPAT3/, CROP S: PATHO M S: PODS S] - Dry weight of leaves lost due to disease-induced defoliation in all leaf cohorts ($g\ m^{-2}$).

WSCDOT [R, /CPAT3/, CROP S: PATHO M S: PODS S] - Dry weight of stems (petioles) lost due to disease-induced defoliation in all leaf cohorts ($g\ m^{-2}$).

WTLFLS [R, LINKAGE, PATHO M S] - Dry weight of leaves lost due to disease-induced defoliation in a leaf cohort ($g\ m^{-2}$).

WTSTLS [R, LINKAGE, PATHO M] - Dry weight of stems (petioles) lost due to disease-induced defoliation in a leaf cohort ($g\ m^{-2}$).

XINDEX [R, /CCOUT/, CONIDI M: OPSEAS S: PATHO S] - Factor expressing the favorability of the environment for infection of the leaves by the pathogen.

XINEXP [R, LINKAGE, PATHO M S] - Expansion rate of the infected leaf area in a leaf cohort ($cm^2\ m^{-2}\ d^{-1}$).

XINFEC [R, LINKAGE, PATHO M S] - Infection rate of healthy leaf area in a leaf cohort ($cm^2\ m^{-2}\ d^{-1}$).

XINFLA [R(i,j), LINKAGE, PATHO M S] - Infectious leaf area of leaf cohort i in state j ($cm^2\ m^{-2}$).

XLATEN [R(i,j), LINKAGE, PATHO M S] - Latently infected leaf area of leaf cohort i in state j (cm^2 m^{-2}).

XLP1 [R, LINKAGE, IPCERC M S] - Time from exposure or inoculation of the pathogen to first lesion showing sporulation; latent period I (d) -- (ILAT < XLP1 ≤ ILAT+15).

XLP50 [R, LINKAGE, IPCERC M S] - Time from exposure or inoculation of the pathogen to 50% of the lesions showing sporulation; latent period 50 (d).

XMLDOT [R, /PLANT4/ PATHO S: other PNUTGRO sub.] - Amount of protein mined from leaves on a given day (g m^{-2} d^{-1}).

XNCONC [R, /CCON2/, CONIDI M S: PATHO S] - Number of conidia in the peanut canopy at the field site under study (# conidia m^{-3}).

XNCONS [R, LINKAGE, CONIDI M S] - Number of conidia that are disseminated from the site of inoculum source (# conidia m^{-3}).

XNSULS [R(i), LINKAGE, PATHO M S] - Number of susceptible leaf sites in leaf cohort i (# sites m^{-2}).

XNVALS [R(i), LINKAGE, PATHO M S] - Number of susceptible leaf sites that are vacant in leaf cohort i (# sites m^{-2}).

ZINCUB [R, /CPAT1/, IPCERC M: PATHO S] - Time from exposure or inoculation of the pathogen to observation of 50% of the possible symptoms (necrotic area); incubation period 50 (d).

ZINFEC [R, /CPAT1/, IPCERC M: PATHO S] - Time from beginning of sporulation to 50% of the lesions releasing spores; infectious period 50 (d).

ZMATUR [R, /CPAT1/, IPCERC M: PATHO S] - Time from first observation of symptoms (necrotic area) to 50% of the lesions showing sporulation; maturation period 50 (d).

APPENDIX F

PNUTGRO FILES MODIFIED IN COUPLING THE LATE LEAFSPOT MODEL

- Sections that were modified in PNUTGRO files are shown in *Italic-Bold* characters.

Filename: COMIO.DAT

```
      INTEGER YEAR
      CHARACTER  *2 INSTE,SITEE,INSTS,SITES,INSTW,SITEW
      CHARACTER  *2 EXPTNO
      CHARACTER  *3 RNAME,RNAMEL,OUT1OP,OUT2OP,OUT3OP,OUT4OP,OUT5OP,
     $               OUT6OP
      CHARACTER  *3 OUTOOP
      CHARACTER  *7 OUT1,OUT2,OUT3,OUT4,OUT5,OUT6
      CHARACTER  *8 EDATE,BDATE
      CHARACTER *12 PEDON
      CHARACTER *12 FILE1,FILE2,FILE3,FILE4,FILE5,FILE6,FILE7
      CHARACTER *12 FILE8,FILE9,FILEA,FILEB,FILEG
      CHARACTER *40 TITLEE,TITLES,TITLEW,TITLET,TITLER
      CHARACTER *60 TAXON
      COMMON/FILES1/FILE1,FILE2,FILE3,FILE4,FILE5
      COMMON/FILES2/FILE6,FILE7,FILE8,FILE9,FILEA,FILEB,FILEG
      COMMON/FILES3/OUT1,OUT2,OUT3,OUT4,OUT5,OUT6
      COMMON/FILES4/NOUTO,NOUT1,NOUT2,NOUT3,NOUT4,NOUT5,NOUT6
      COMMON/FILES4/OUTOOP,OUT1OP,OUT2OP,OUT3OP,OUT4OP,OUT5OP,OUT6OP
      COMMON/ID1/TITLEE,SITEE,INSTE,EXPTNO
      COMMON/ID2/ISOILT,PEDON,TAXON
      COMMON/ID3/TITLEW,SITEW,INSTW,BDATE,EDATE,YEAR,NPWFIL,NWFDIR
      COMMON/ID4/TITLET,TITLER
      COMMON/SENST/INDSEN,IPLTRL,LWATER,SROWSP,SBETN,IIRRS,SDSOIL(3),
     2             STHETA(3),SEFFIR,NLSOIL,NLVAR
      COMMON/STRESS/CWSV,CWSR
      COMMON/DATA1/NTRT,NFEXP,NWFILE,NSFILE,DSFILE,NSENS,PHINT
      COMMON/DATA2/NREP,KYR,IPY,JULCHK,INITDA,KOUTWA,KOUTGR,KOUTDS
      COMMON/DATA3/MON(12),RNAME(12),RNAMEL(12)
      COMMON/COMPAR/XSDYLD,XSDWT,XSDSM,XSPP,XLAIR4,XBIOM,
     +              XSTALK,IFLRJD,MATJD,XPDYLD,XTHRES,XPCMAT,
     +              IFFSP,IFFS,XHI
```

Filename: CROP.FOR

```
$STORAGE:2
      SUBROUTINE CROP
$INCLUDE: 'COMGRO.DAT'
$INCLUDE: 'COMIO.DAT'
$INCLUDE: 'COMDIS.DAT'
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
      IF (N .GT. 1) GO TO 100
C-----------------------------------------------------------------------
C
C     INITIALIZE VARIABLES FOR NEW RUN
C
C-----------------------------------------------------------------------
      SEEDNO = 0.0
      SDGR = 0.0
      ALPGR = 1.0
      ALPHA = 1.0
      SLDOT = 0.0
      SLNDOT = 0.0
      SSNDOT = 0.0
      SSDOT = 0.0
      SRDOT = 0.0
      SNIDOT = 0.0
      SWIDOT = 0.0
      WSHIDT = 0.0
      SDPDOT = 0.0
      SDIDOT = 0.0
      PUNDOT = 0.0
      PUNCSD = 0.0
      PUNCTR = 0.0
      GAMMAS = 0.0
      GAMMAL = 0.0
      GAMMAR = 0.0
      XMLDOT = 0.0
      XMSDOT = 0.0
      XMSHDT = 0.0
      XMRDOT = 0.0
      XMSH = 0.0
      XML = 0.0
      XMS = 0.0
      XMR = 0.0
      WLIDOT = 0.0
      XLIDOT = 0.0
      DISLA = 0.0
      TOTCON = 0.0
      PDEFOL = 0.0
      TOTWT = 0.0
      TOPWT = 0.0
      WTMAIN = 0.0
      RTWT = 0.0
      WTLF = 0.0
```

```
      WLPOS = 0.0
      STMWT = 0.0
      PODWT = 0.0
      WTABRT = 0.0
      WTSHMT = 0.0
      PODNO = 0.0
      PCTMAT = 0.0
      DAMSD = 0.0
      XSHELL = 0.0
      SHELWT = 0.0
      XSEED = 0.0
      SDWT = 0.0
      XPOD = 0.0
      PG = 0.0
      PGAVL = 0.0
      PGNET = 0.0
      SLA = F
      XLAI = 0.0
      XHLAI = 0.0
      SLAIR4 = 0.0
      GRORT = 0.0
      DTT = 0.0
C-----------------------------------------------------------------------
C
C     THIS NEXT STATEMENT SHOULD BE REMOVED AFTER TURFAC
C     IS FIXED SO THAT IT IS CALCULATED PRIOR TO PLANT EMERG.
C
C-----------------------------------------------------------------------
      WTSHM = 0.
      WTSHMT = 0.0
      TURFAC = 1.0
      SWFAC = 1.0
      PCNIT = 4.5
C
      CALL RHUMID
      CALL CONIDI
      CALL PATHO
C
  100 CONTINUE
      WLIDOT = 0.0
C-----------------------------------------------------------------------
C
C     CALL only WATer BALance routine untill planting date
C
C-----------------------------------------------------------------------
      CALL WATBAL
      IF (N .LT. (IPLT-IWATER+1)) RETURN
      CALL WCALC
C
      CALL RHUMID
      CALL CONIDI
C
      CALL GPHEN
C-----------------------------------------------------------------------
```

```
C
C-----------------------------------------------------------------------
      IF (N .LT. NVEGO) GO TO 200
C-----------------------------------------------------------------------
C
C     CALL SUBROUTINE TO CALCULATE GROSS PHOTOSYNTHESIS
C     AND MAINTENANCE RESPIRATION COEFFICIENTS
C
C-----------------------------------------------------------------------
      CALL PHOTO
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
      PGAVL = PG - RO * WTMAIN - RP * PG
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
      CALL GROW
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
      PGAVL = AMIN1(PGAVL,PGNET)
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
  200 CONTINUE
      IF (N .LT. NVEGO) GO TO 400
      IF (TMIN .LT. FREEZ1) CALL FREEZE
C
C-----------------------------------------------------------------------
C
C     CALCULATE POSITIVE GROWTH AND CUMULATIVE LEAF WEIGHT GROWTH (WLPOS
C
C-----------------------------------------------------------------------
      DWPOS = PGAVL / ALPGR
      DWPOS = AMAX1(0.0,DWPOS)
      DWLPOS = XLF * DWPOS
      GRORT = XRT * DWPOS / PLTPOP
      WLPOS = WLPOS + DWLPOS
C
C **********************************************************************
C *                                                                    *
C *       INTEGRATION OF LEAFSPOT DISEASE MODEL                        *
C *                                                                    *
C **********************************************************************
C
      CALL PATHO
C
C-----------------------------------------------------------------------
C
C     GOVERNING MODEL EQUATIONS (WILKERSON ET AL., 1983)
C
C-----------------------------------------------------------------------
      WDOT = PGAVL / ALPGR - SLDOT - SSDOT - WLIDOT - SWIDOT - WSHIDT-
```

```
     +     SRDOT - WTABRT - WLCDOT - WSCDOT
      WLDOT = XLF * PGAVL / ALPGR - SLDOT - XMLDOT - WLIDOT - WLCDOT
      WSDOT = XSTM * PGAVL / ALPGR - XMSDOT - SSDOT - WSCDOT
      WSHDOT = XSHELL * PGAVL / ALPGR - XMSHDT - WSHIDT - WTABRT
      WSDDOT = XSEED * PGAVL / ALPGR + ALPHA*(XMSHDT + XMLDOT + XMSDOT+
     +     XMRDOT) - SWIDOT
      WPDOT = WSHDOT + WSDDOT
      WRDOT = XRT * PGAVL / ALPGR - SRDOT - XMRDOT
      TOTWT = TOTWT + WDOT
      TOPWT = TOPWT + WSDOT + WLDOT + WPDOT
      WTLF = WTLF + WLDOT
      STMWT = STMWT + WSDOT
      SDWT = SDWT + WSDDOT
      SHELWT = SHELWT + WSHDOT
      RTWT = RTWT + WRDOT
      PODWT = PODWT + WPDOT
      TOTWT = AMAX1(0.,TOTWT)
      IF (TOPWT .LT. 0.00001) GO TO 250
      TOPWT = AMAX1(0.,TOPWT)
      WTLF = AMAX1(0.,WTLF)
      IF (STMWT .LT. 0.00001) GO TO 250
      STMWT = AMAX1(0.,STMWT)
      SDWT = AMAX1(0.,SDWT)
      SHELWT = AMAX1(0.,SHELWT)
      IF (RTWT .LT. 0.00001) GO TO 250
      RTWT = AMAX1(0.,RTWT)
      PODWT = AMAX1(0.,PODWT)
C-----------------------------------------------------------------------
C
C     ONLY THE FIRST PART OF SEED WEIGHT IS CONSIDERED TO BE ACTIVE
C     TISSUE FOR WHICH THERE IS A MAINTENANCE COST.  ONCE SEED WEIGHT
C     REACHES SHELL WEIGHT, MAINTENANCE COSTS FOR SEEDS DO NOT INCREASE.
C
C-----------------------------------------------------------------------
      WSDMAN = AMIN1(SDWT,SHELWT)
      WTMAIN = TOTWT - SDWT + WSDMAN
C-----------------------------------------------------------------------
C
C     INTEGRATE INSECT DAMAGE
C
C-----------------------------------------------------------------------
      DAMSD = DAMSD + SNIDOT
      PUNCSD = PUNCSD + SDPDOT
      SEEDNO = SEEDNO - SDIDOT
      PUNCTR = PUNCTR + PUNDOT
C-----------------------------------------------------------------------
C
C     CALCULATE POSITIVE GROWTH AND CUMULATIVE LEAF WEIGHT GROWTH (WLPOS
C      (Now calculated earlier in this subroutine -- Gaétan Bourgeois)
C-----------------------------------------------------------------------
C     DWPOS = PGAVL / ALPGR
C     DWPOS = AMAX1(0.0,DWPOS)
C     DWLPOS = XLF * DWPOS
C     GRORT = XRT * DWPOS / PLTPOP
```

```
C     WLPOS = WLPOS + DWLPOS
C-----------------------------------------------------------------------
C
C     CALCULATE WEIGHTED CANOPY SLA BASED ON NEW LEAF GROWTH OCCURRING
C     AT A SPECIFIC LEAF AREA OF CM2/G
C
C-----------------------------------------------------------------------
      IF (WTLF .LE. 0.0001) GO TO 300
      SLA = (SLA * (WTLF - DWLPOS) + F * DWLPOS)/WTLF
  300 CONTINUE
C-----------------------------------------------------------------------
C
C     CALCULATE REMAINING PROTEIN IN SHELLS, LEAVES, STEMS, AND ROOTS
C     THAT CAN BE MINED (PLANT N-BALANCE)
C
C-----------------------------------------------------------------------
      XMSH = XMSH + BETASH*XSHELL*DWPOS-XMSHDT-GAMMSH*(WTABRT+WTSHMT)
      XML = XML + BETAL * DWLPOS - XMLDOT - GAMMAL*(SLNDOT+WLIDOT
     $       + WLCDOT)
        XML = AMAX1(0, XML)
      XMS = XMS + BETAS * XSTM * DWPOS - XMSDOT - GAMMAS * (SSNDOT
     $       + WSCDOT)
        XMS = AMAX1(0, XMS)
      XMR = XMR + BETAR * XRT * DWPOS - XMRDOT - GAMMAR * SRDOT
      IF (XMR .LE. 1.0E-30) XMR = 0.0
  400 CONTINUE
C-----------------------------------------------------------------------
C
C     CALCULATE AREA OF LEAVES FROM LEAF WEIGHT AND SPECIFIC LEAF AREA
C
C-----------------------------------------------------------------------
      AREALF = SLA * WTLF
      IF (AREALF .LE. 0.00001) GO TO 500
C-----------------------------------------------------------------------
C
C     CALCULATE INSECT CAUSED DEFOLIATION AND PERCENT DISEASED LEAF AREA
C
C-----------------------------------------------------------------------
      PDEFOL = (TOTCON / (AREALF + TOTCON)) * 100.0
      DISPER = PERDIS
  500 CONTINUE
C-----------------------------------------------------------------------
C
C     CALCULATE LEAF AREA INDEX AND "HEALTHY" OR NON-DISEASED LEAF AREA
C     INDEX
C
C-----------------------------------------------------------------------
      XLAI = AREALF / GAREA
      DISLA = AREALF * PERDIS / 100
      AREAH = AREALF - DISLA
      XHLAI = AREAH / GAREA
      SLAIR4 = AMAX1(XLAI,SLAIR4)
      RETURN
  250 CONTINUE
```

```
      IF (N .LT. NVEG1) NVEG1 = N
      IF (N .LT. JPEND) JPEND = N
      IF (N .LT. NR0) NR0 = N
      IF (N .LT. NR1) NR1 = N
      IF (N .LT. NPOD0) NPOD0 = N
      IF (N .LT. NR4) NR4 = N
      IF (N .LT. NDLEAF) NDLEAF = N
      IF (N .LT. NDSET) NDSET = N
      IF (N .LT. NR7) NR7 = N
      NR8 = N
      WRITE (*    ,275) N
      WRITE (NOUT1,275) N
  275 FORMAT(/10X,'PLANT DIED DUE TO EXTREME STRESS ON DAY ',
     + I3,' OF SIMULATION',/)
      RETURN
      END
```

Filename: GRO.FOR

```
$STORAGE:2
$INCLUDE: 'COMGRO.DAT'
$INCLUDE: 'COMSOI.DAT'
$INCLUDE: 'COMIO.DAT'
$INCLUDE: 'COMDIS.DAT'
C-----------------------------------------------------------------------
C
C     MAIN DRIVER FOR PNUTGRO ibsnat VERSION
C          May 1989       PNUTGRO V1.02
C
C-----------------------------------------------------------------------
      DIMENSION IMON(12)
      CHARACTER*1 ANS
      CHARACTER*3 TNAME(12),TNAMEL(12)
      CHARACTER*12 FILEC,FILED
      LOGICAL*4 FEXIST
      DATA IMON/31,28,31,30,31,30,31,31,30,31,30,31/
      DATA TNAME /'JAN','FEB','MAR','APR','MAY','JUN','JUL','AUG',
     +'SEP','OCT','NOV','DEC'/
      DATA TNAMEL/'jan','feb','mar','apr','may','jun','jul','aug',
     +'sep','oct','nov','dec'/
C-----------------------------------------------------------------------
C
C**** initialize
C
C-----------------------------------------------------------------------
      NSENS = 0
      NREP = 0
      NOUTO = 40
      NOUT1 = 41
      NOUT2 = 42
      NOUT3 = 43
      NOUT4 = 44
      NOUT5 = 45
      NOUT6 = 46
      OUTOOP = 'YES'
      OUT1OP = 'YES'
      OUT2OP = 'YES'
      OUT3OP = 'YES'
      OUT5OP = 'YES'
      OUT6OP = 'YES'
      KOUTWA = 2
      KOUTGR = 2
      KOUTDS = 2
      GAREA = 1.E04
      AMTMIN = 2.54
           DO 100 I = 1,12
           MON(I) = IMON(I)
           RNAME(I) = TNAME(I)
           RNAMEL(I) = TNAMEL(I)
  100      CONTINUE
      INQUIRE (FILE = 'BATCH.$$$',EXIST = FEXIST)
```

```
      IF (FEXIST) THEN
         OUTOOP = ' NO'
         OPEN(5,FILE = 'BATCH.$$$')
      ENDIF
      IF (OUTOOP .EQ. 'YES') CALL CLEAR
      IF (OUTOOP .EQ. 'YES') CALL INTRO
      IF (OUTOOP .EQ. ' NO') READ(5,1800) ANS
      CALL IPCROP
C-----------------------------------------------------------------------
C
C     simulation loop
C
C-----------------------------------------------------------------------
  200 NREP = NREP + 1
      INDSEN = -1
      IF (OUTOOP .EQ. 'YES') CALL CLEAR
      CALL IPEXP
      FILEC=FILEB
      WRITE(FILEC(12:12),301)
  301 FORMAT('C')
      FILED=FILEB
      WRITE(FILED(12:12),302)
  302 FORMAT('D')
  300 IF (OUTOOP .EQ. 'YES') CALL CLEAR
      IF (OUTOOP .EQ. 'YES') WRITE (*,400)
  400     FORMAT(2X,'WHAT WOULD YOU LIKE TO DO ?',
     +         //2X,'0)   RUN SIMULATION.',
     +          /2X,'1)   SELECT SENSITIVITY ANALYSIS OPTIONS. ',
     +          /2X,'2)   SELECT SIMULATION OUTPUT OPTIONS.',
     +         //2X,'<=== CHOICE? [ DEFAULT = 0 ]')
      READ (5,500,ERR = 300) NSENS
  500 FORMAT(I2)
      IF (NSENS .LT. 0 .OR. NSENS .GT. 2) GO TO 300
      IF (NSENS .EQ. 0) GO TO 600
      IF (NSENS .EQ. 1) INDSEN = 1
      IF (NSENS .EQ. 1) CALL IPSENS
      IF (NSENS .EQ. 2) CALL IPFREQ
      GO TO 300
  600 CONTINUE
      IF (INDSEN .GT. 0) GO TO 800
      IPLTRL = IPLT
      LWATER = IWATER
      SROWSP = ROWSPC
      SBETN  = BETN
      IIRRS  = IIRR
      SEFFIR = EFFIRR
           DO 700 I = 1,3
           SDSOIL(I) = DSOIL
           STHETA(I) = THETAC
  700      CONTINUE
      NLVAR  = IVARTY
      NLSOIL = ISOILT
      NPWFIL = NWFDIR
      NDISRC = JDISWT
```

```
      GO TO 900
  800 IVARTY = NLVAR
      IPLT  = IPLTRL
      IWATER = LWATER
      ROWSPC = SROWSP
      BETN   = SBETN
      IIRR   = IIRRS
      DSOIL  = SDSOIL(1)
      THETAC = STHETA(1)
      IF (IIRR .EQ. 3) EFFIRR = SEFFIR
      ISOILT = NLSOIL
      NWFDIR = NPWFIL
      JDISWT = NDISRC
  900 CONTINUE
      IF (OUTOOP .EQ. 'YES') WRITE (*,1000) NREP
 1000 FORMAT(T21,'<=== RUN ',I3,' IDENTIFIER ?')
      READ (5,1100) TITLER
 1100 FORMAT(A40)
      IF (TITLER .EQ. '                                        ')
     +     TITLER = TITLET
      CALL IPTRT
      IF (NREP .GT. 1) GO TO 1300
      OPEN (UNIT = NOUTO,FILE = 'SIM.DIR')
      OPEN (UNIT = NOUT1,FILE = OUT1)
      OPEN (UNIT = NOUT2,FILE = OUT2)
      OPEN (UNIT = NOUT3,FILE = OUT3)
      OPEN (UNIT = NOUT4,FILE = OUT4)
      OPEN (UNIT = NOUT5,FILE = OUT5)
      OPEN (UNIT = NOUT6,FILE = OUT6)
      WRITE (NOUTO,1200) OUT1,OUT2,OUT3,OUT4,OUT5,OUT6
 1200 FORMAT(1X,5(A7,','),A7)
 1300 CONTINUE
      INQUIRE(FILE=FILEC,EXIST=FEXIST)
      IF(.NOT.FEXIST) FILEC='                '
      INQUIRE(FILE=FILED,EXIST=FEXIST)
      IF(.NOT.FEXIST) FILED='                '
      WRITE (NOUTO,1400) TITLER,FILEB,FILEC,FILED,FILEG
 1400 FORMAT(1X,A40,4(1X,A12))
      N = 0
      MAXWTH = 1000
      IF (IPLT .LT. IWATER) IPLT = IPLT+JULCHK
      CALL OPECHO
 1500 N = N + 1
      CALL IPWTH
      IF (N .GT. MAXWTH) GO TO 1600
      CALL CROP
      CALL OPSEAS
      IF (N .LT. NR8) GO TO 1500
 1600 CALL OPHARV
      CLOSE(11)
      IF (OUTOOP .EQ. 'YES') WRITE (*,1700)
 1700 FORMAT(/1X,' MORE SIMULATIONS ?'',
     +       /1X,' <===  Y OR N? [DEFAULT "Y"] ')
      READ (5,1800) ANS
```

```
1800 FORMAT(A1)
     IF (ANS .EQ. 'y' .OR. ANS .EQ. 'Y' .OR. ANS .EQ. ' ') GO TO 200
     ENDFILE(NOUT0)
     ENDFILE(NOUT1)
     ENDFILE(NOUT2)
     ENDFILE(NOUT3)
     ENDFILE(NOUT4)
     ENDFILE(NOUT5)
     ENDFILE(NOUT6)
     CLOSE (NOUT0)
     CLOSE (NOUT1)
     CLOSE (NOUT2)
     CLOSE (NOUT3)
     CLOSE (NOUT4)
     CLOSE (NOUT5)
     CLOSE (NOUT6)
     STOP
     END
```

Filename: IPEXP.FOR

```
$STORAGE: 2
      SUBROUTINE IPEXP
C-----------------------------------------------------------------------
C
C***  EXPERIMENT AND TREATMENT SELECTION.
C
C-----------------------------------------------------------------------
$INCLUDE: 'COMGRO.DAT'
$INCLUDE: 'COMSOI.DAT'
$INCLUDE: 'COMIO.DAT'
$INCLUDE: 'COMDIS.DAT'
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
      CHARACTER*12 DWFILE
      INTEGER TRTNO
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
      IF (NREP .GT. 1) GO TO 100
      NFEXP = 1
      NLEXP = -1
      NLTRT = -1
  100 CONTINUE
      OPEN (6, FILE = 'PNEXP.DIR',STATUS = 'OLD')
      IF (OUTOOP .EQ. 'YES') WRITE (*,200)
  200 FORMAT (T47,'INST.',T54,'SITE',T60,'EXPT.',
     +/T6,'CASE STUDY EXPERIMENTS ',T48,'ID',T55,'ID',
     +T61,'NO',T66,'YEAR',/T6,35('-'),T47,'----',T54,'----',
     +           T60,'----',T66,'----')
      I = 0
      II = 0
  300 I = I + 1
      II = II+1
      READ (6,400, END = 800) INSTE,SITEE,YEAR,EXPTNO,TITLEE
  400 FORMAT (2A2,I2,A2,1X,A40,///)
      IF (OUTOOP .EQ. 'YES') WRITE (*,500) I,TITLEE,INSTE,SITEE,
     +   EXPTNO,YEAR
  500 FORMAT ( T2,I2,')',T7,A40,T48,A2,T55,A2,T61,A2,T66,'19',I2)
      IF (II .LT. 15) GO TO 300
      IF (OUTOOP .EQ. 'YES') WRITE (*,600)
  600 FORMAT(/,'  More.... PRESS ENTER KEY')
      READ (5,700) ANS
  700 FORMAT(A1)
      II = 0
      GO TO 300
  800 REWIND 6
      I = I - 1
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
  900 IF (OUTOOP .EQ. 'YES') WRITE (*,1000) NFEXP
```

```
1000 FORMAT(/,1X,I2,']',2X,'<=== CASE STUDY SELECTED',
    +/6X,'<--- NEW SELECTION?  ')
     READ (5,1100,ERR = 900) N
1100 FORMAT(I2)
     IF (N .LT. 0 .OR. N .GT. I) GO TO  900
     IF (N .NE. 0) NFEXP = N
          DO 1500 I = 1,NFEXP
          READ (6,1200) INSTE,SITEE,YEAR,EXPTNO,TITLEE,FILE1,FILE2
          READ (6,1300) FILE4,FILE5,FILE6,FILE7,FILE8,FILE9
          READ (6,1400) FILEA,FILEB,OUT1,OUT2,OUT3,OUT4,OUT5
          READ (6,1420) FILEG,OUT6
1200 FORMAT (2A2,I2,A2,1X,A40,2(1X,A12))
1300 FORMAT (A12,5(1X,A12))
1400 FORMAT (A12,1X,A12,5(1X,A7))
1420 FORMAT (A12,1X,A7)
1500      CONTINUE
     CLOSE (6)
C-------------------------------------------------------------------------
C
C-------------------------------------------------------------------------
     OPEN (7,FILE = 'WTH.DIR',STATUS = 'OLD')
     NWFDIR = 0
1600 NWFDIR = NWFDIR + 1
     READ (7,1700,END = 1800,ERR = 2000) DWFILE
1700 FORMAT (63X,A12)
     IF ( DWFILE .EQ. FILE1) GO TO 2200
     GO TO 1600
1800 WRITE (*,1900) FILE1
1900 FORMAT(1X,'OOPS! Weather data file ',A12,' missing in WTH.DIR.',
    +1X,'PRESS <Ctrl-Break> keys and fix the problem.')
     READ (5,3700) ANS
     GO TO 2200
2000 WRITE (*,2100)
2100 FORMAT(1X,'OOPS! Format data mis-matchin file WTH.DIR.',
    +1X,'PRESS <Ctrl-Break> keys and fix the problem.')
     READ (5,3700) ANS
2200 CONTINUE
     CLOSE (7)
     IF (OUTOOP .EQ. 'YES') CALL CLEAR
     IF (NFEXP .NE. NLEXP) NTRT = 1
     OPEN (18,FILE = FILE8,STATUS = 'OLD')
     IF (OUTOOP .EQ. 'YES') WRITE (*,2300) TITLEE
2300 FORMAT (T2,'TRT',T47,'INST.',T54,'SITE',T60,'EXPT.',
    +/,T2,'NO.',T7,A40,T48,'ID',T55,'ID',T61,'NO',
    +          T66,'YEAR',/,T2,'---',T7,40('-'),T47,'----',
    +          T54,'----',T60,'----',T66,'----')
2400 READ  (18,2500, END = 2700) TRTNO,TITLET
     READ (18,*,END = 3200) IWATER,IPLT,PLTPOP,ROWSPC,SDEPTH,IIRR,
    +     ISWNIT,EFFIRR,DSOIL,THETAC,PHINT,IPHN,JDISWT
     IF (IPHN .NE. 0) READ (18,*  ) (JULPHN(I),I = 1,11)
     IF (OUTOOP .EQ. 'YES') WRITE (*,2600) TRTNO,TITLET,INSTE,SITEE,
    +   EXPTNO,YEAR
2500 FORMAT (9X,I2,1X,A40,2(1X,I4))
2600 FORMAT ( T2,I2,')',T7,A40,T48,A2,T55,A2,T61,A2,T66,'19',I2)
```

```
      GO TO 2400
 2700 REWIND 18
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
 2800 IF (OUTOOP .EQ. 'YES') WRITE (*,2900) NTRT
 2900 FORMAT(/,1X,I2,']',2X,'<=== TREATMENT SELECTED',
     +/6X,'<--- NEW SELECTION?' )
      READ (5,3000,ERR = 2800) N
 3000 FORMAT(I2)
      IF (N .LT. 0 .OR. N .GT. TRTNO) GO TO  2800
      IF (N .NE. 0) NTRT = N
 3100 READ (18,2500,END = 3200) TRTNO,TITLET,ISOILT,IVARTY
      READ (18,*,END = 3200) IWATER,IPLT,PLTPOP,ROWSPC,SDEPTH,IIRR,
     +     ISWNIT,EFFIRR,DSOIL,THETAC,PHINT,IPHN,JDISWT
      IF (TRTNO .NE. NTRT) GO TO 3100
      GO TO 3400
 3200 IF (TRTNO .EQ. NTRT) GO TO 3400
      WRITE (*,3300) NTRT,FILE8
 3300 FORMAT(1X,'OOPS! Treatment ',I2,' missing in file ',A12,'.',
     +1X,'PRESS <Ctrl-Break> keys and fix the problem.')
      READ (5,3700) ANS
      STOP
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
 3400 IF (IIRR .NE. 3) GO TO 3600
           DO 3500 I = 1,3
           SDSOIL(I) = DSOIL
           STHETA(I) = THETAC
 3500      CONTINUE
 3600 CLOSE (18)
      BETN = 1./(ROWSPC*PLTPOP)
      JULCHK = 365
      IF ((YEAR/4)*4 .EQ. YEAR) JULCHK = 366
 3700 FORMAT(A1)
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
      IF (NFEXP .EQ. NLEXP .AND. NTRT .EQ. NLTRT) GO TO 4000
 3800 IPLTRL = IPLT
      LWATER = IWATER
      SROWSP = ROWSPC
      SBETN  = BETN
      IIRRS  = IIRR
      SEFFIR = EFFIRR
           DO 3900 I = 1,3
           SDSOIL(I) = DSOIL
           STHETA(I) = THETAC
 3900      CONTINUE
      VRNAME = '                  '
      TAXON  = '                      '
      RACEID = '                      '
      NLVAR = IVARTY
```

```
      NLSOIL = ISOILT
      NPWFIL = NWFDIR
      NDISRC = JDISWT
 4000 NLEXP = NFEXP
      NLTRT = NTRT
      RETURN
      END
```

Filename IPFREQ.FOR

```
$STORAGE:2
      SUBROUTINE IPFREQ
$INCLUDE: 'COMIO.DAT'
      CHARACTER*1 LINE(72)
  100 CONTINUE
      IF (OUTOOP .EQ. 'YES')  THEN
      CALL CLEAR
      WRITE (*, 200) OUT1OP,OUT2OP,OUT3OP,OUT5OP,KOUTGR,KOUTWA,OUTOOP
     +                    ,OUT6OP,KOUTDS
  200 FORMAT(2X,'OUTPUT OPTIONS AND CURRENT SELECTIONS',/,
     +       '=========================================',/,
     +'  0. RETURN TO MENU',//,
     +'  1. FILE OUT1 ( save all screen outputs) .......',A3,/,
     +'  2. FILE OUT2 ( save biomass data ) ............',A3,/,
     +'  3. FILE OUT3 ( save weather, soil water data)..',A3,/,
     +'  4. FILE OUT5 ( summary of simulation ) ........',A3,/,
     +'  5. OUTPUT FREQUENCY FOR OUT2 ..................',I3,' DAYS',/,
     +'  6. OUTPUT FREQUENCY FOR OUT3 ..................',I3,' DAYS',/,
     +'  7. WRITE INTERMEDIATE RESULTS TO SCREEN .......',A3,/,
     +'  8. FILE OUT6 ( save disease data) .............',A3,/,
     +'  9. OUTPUT FREQUENCY FOR OUT6 ..................',I3,' DAYS',/,
     +' <== SELECTION BY NUMBER? [ DEFAULT=0 ]')
      ENDIF
      READ (5,300,ERR = 100) MENU
  300 FORMAT(I2)
      IF (MENU .LT. 0 .OR. MENU .GT. 9) GO TO 100
      IF (MENU .EQ. 0) GO TO 2200
      GO TO (400,600,800,1000,1200,1800,2000,1120,1920),MENU
  400 IF (OUT1OP .EQ. 'YES') GO TO 500
      OUT1OP = 'YES'
      GO TO 100
  500 OUT1OP = ' NO'
      GO TO 100
  600 IF (OUT2OP .EQ. 'YES') GO TO 700
      OUT2OP = 'YES'
      GO TO 100
  700 OUT2OP = ' NO'
      GO TO 100
  800 IF (OUT3OP .EQ. 'YES') GO TO 900
      OUT3OP = 'YES'
      GO TO 100
  900 OUT3OP = ' NO'
      GO TO 100
 1000 IF (OUT5OP .EQ. 'YES') GO TO 1100
      OUT5OP = 'YES'
      GO TO 100
 1100 OUT5OP = ' NO'
      GO TO 100
 1120 IF (OUT6OP .EQ. 'YES') GO TO 1130
      OUT6OP = 'YES'
      GO TO 100
 1130 OUT6OP = ' NO'
```

```
      GO TO 100
C
 1500 WRITE (*,1600)
 1200 IF (OUTOOP .EQ. 'YES') WRITE (*,1300)
 1300 FORMAT(/,
     +' <=== OUTPUT FREQUENCY FOR OUT2 [BIOMASS COMPONENTS]?')
      READ (5,1400) LINE
 1400 FORMAT(72A1)
      CALL VERIFY(LINE,FREQ,FLAG)
      IF (FLAG .GT. 0 .OR. FREQ .LT. 1 .OR. FREQ .GT. 99) GO TO 1500
      IF (FREQ  .GT. 0) KOUTGR = FREQ
      GO TO 100
 1600 FORMAT(3X,'Output frequency must be a number between',
     + ' 1 and 99')
 1700 WRITE (*,1600)
 1800 IF (OUTOOP .EQ. 'YES') WRITE (*,1900)
 1900 FORMAT(/,' <=== OUTPUT FREQUENCY FOR OUT3 [WATER BALANCE AND ',
     + 'WEATHER COMPONENTS] ?')
      READ (5,1400) LINE
      CALL VERIFY(LINE,FREQ,FLAG)
      IF (FLAG .GT. 0 .OR. FREQ  .LT. 1 .OR. FREQ .GT. 99) GO TO 1700
      IF (FREQ .GT. 0) KOUTWA = FREQ
      GO TO 100
 1910 WRITE (*,1600)
 1920 WRITE (*,1930)
 1930 FORMAT(/,
     +' <=== OUTPUT FREQUENCY FOR OUT6 [DISEASE COMPONENTS]?')
      READ (5,1400) LINE
      CALL VERIFY(LINE,FREQ,FLAG)
      IF (FLAG .GT. 0 .OR.  FREQ .LT. 0 .OR. FREQ .GT. 99) GO TO 1910
      IF (FREQ  .GT. 0) KOUTDS = FREQ
      GO TO 100
C
 2000 IF (OUTOOP .EQ. 'YES') GO TO 2100
      OUTOOP = 'YES'
      GO TO 100
 2100 OUTOOP = ' NO'
      GO TO 100
 2200 RETURN
      END
```

Filename: IPSENS.FOR

```
$STORAGE:2
      SUBROUTINE IPSENS
C-------------------------------------------------------------------------------
C
C-------------------------------------------------------------------------------
$INCLUDE: 'COMGRO.DAT'
$INCLUDE: 'COMSOI.DAT'
$INCLUDE: 'COMIO.DAT'
$INCLUDE: 'COMDIS.DAT'
      CHARACTER*3 RMM,RM,RMS,RPS,RSS
      CHARACTER*1 LINE(72),DASH
      DATA NDX1/1/
C-------------------------------------------------------------------------------
C
C-------------------------------------------------------------------------------
      IF (NDX1 .EQ. 0) GO TO 400
      IF (OUTOOP .EQ. 'YES') CALL CLEAR
      IF (OUTOOP .EQ. 'YES') WRITE (*,100)
  100 FORMAT(/////////26X,'MANAGEMENT / SENSITIVITY ANALYSIS.',
     +/26X,          '=====================================',
     +/T10,'Following options are initially assigned values according',
     +/T10,'to the case study and treatment selected.  With these ',
     +/T10,'default values you will be able to validate the simulation',
     +/T10,'results.  You change the default values to evaluate alter-',
     +/T10,'nate management strategies or make tactical decisions.',
     +/T10,'If you choose not to change any of the current selections,',
     +/T10,'Press ^Q┘ in response to questions.  NOTE: THIS MESSAGE ',
     +/T10,'WILL NOT BE REPEATED')
      IF (OUTOOP .EQ. 'YES') WRITE (*,200)
  200 FORMAT(/55X,' Press ^Q┘ to continue')
      READ (5,300)ANS
  300 FORMAT(3A1)
  400 CONTINUE
      NSENS=0
      ITEMP=NWFDIR
      NWFDIR=NPWFIL
      CALL IDWTH
      NWFDIR=ITEMP
      NSENS=1
  500 IF (OUTOOP .EQ. 'YES') CALL CLEAR
      CALL NAILUJ(IPLTRL,YEAR,RPS,IDP)
      CALL NAILUJ(LWATER,YEAR,RSS,IDS)
           DO 600 I = 1,72
           LINE(I) = ' '
  600      CONTINUE
      PLTPOP = 1. / (SROWSP*SBETN)
      IF (OUTOOP .EQ. 'YES') WRITE (*, 700) NLVAR,VRNAME,RSS,IDS,RPS,
     +     IDP,PLTPOP,IIRRS,NLSOIL,TAXON,FILE1,NDISRC,RACEID
  700 FORMAT(2X,'MANAGEMENT / SENSITIVITY ANALYSIS CHOICES',/,
     +     1X,'=========================================',//,
     +/'  0. RETURN TO THE MENU        ',/,
     +/'  1. Variety Selection  .....[ ','No. ',I2,1X,A16,/,
```

```
     +'  2. Simulation/Planting Date.....[ ',A3,1X,I2,'/',A3,I2,/,
     +'  3. Planting Density.............[ ',F6.2,' PLANTS/M2',/,
     +'  4. Irrigation Strategy..........[ ','No. ',I2,/,
     +'  5. Soil Type....................[ ','No. ',I2,1X,A20,/,
     +'  6. Weather data Selection.......[ ',A12,/,
     +'  7. Pathogen Race Selection......[ ','No. ',I2,1X,A25,//,
     +'  <-- ENTER CHOICE [ DEFAULT = 0] ')
      READ (5,800,ERR = 500) MENU
  800 FORMAT(I2)
      IF (MENU .LT. 0 .OR. MENU .GT. 7) GO TO 500
      IF (MENU .EQ. 0) GO TO 4800
      GO TO (900,1000,2600,3300,4600,4700,4750),MENU
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
  900 CALL IPVAR
      GO TO 500
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
 1000 CONTINUE
      CALL NAILUJ(IPLTRL,YEAR,RMS,IDYS)
      CALL NAILUJ(IPLT,YEAR,RM,IDY)
      GO TO 1500
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
 1100 CALL NAILUJ(INITDA,YEAR,RM,IDY)
      WRITE (*,1200) RM,IDY-1
 1200 FORMAT(10X,'ERROR: Insufficient weather data for this planting',
     +' date.',/10X,'       Please select date after ',A3,'-',I2,'.')
      GO TO 1500
 1300 WRITE (*,1400)
 1400 FORMAT(10X,'Error in date specification. Please specify 3 letters'
     +/10X,'for the name of the month and 2 digits for the day number',
     +/10X,'(i.e. JUN-15)')
 1500 IF (OUTOOP .EQ. 'YES') WRITE (*,1600) RMS,IDYS,RM,IDY
 1600 FORMAT(1X,A3,'-',I2,3X,'<=== SELECTED PLANTING DATE.',
     +      /1X,A3,'-',I2,3X,'<=== CASE STUDY PLANTING DATE.',
     +/10X,'<--- NEW VALUE? (Ex. JUN-15)')
      READ (5,1700,ERR = 1300) RMM,DASH,IDYY
 1700 FORMAT(A3,A1,I2)
      IF (RMM .EQ. '   ' .AND. IDYY .EQ. 0) GO TO 1800
      IF (DASH .NE. '-' .OR. IDYY .LT. 0 .OR. IDYY .GT. 31) GO TO 1300
      IDUMM = JULIAN(IDYY,RMM,YEAR)
      IF (IDUMM .GT. 366) GO TO 1300
      IPLTRL = IDUMM
 1800 CONTINUE
C-----------------------------------------------------------------------
C     IF (IPLTRL .LT. INITDA) GO TO 600
C-----------------------------------------------------------------------
      CALL NAILUJ(LWATER,YEAR,RMS,IDYS)
      CALL NAILUJ(IWATER,YEAR,RM,IDY)
      GO TO 2000
```

```
1900 WRITE (*,1400)
2000 IF (OUTOOP .EQ. 'YES') WRITE (*,2100) RMS,IDYS,RM,IDY
2100 FORMAT(1X,A3,'-',I2,3X,'<=== SELECTED SIMULATION INITIATION DATE.'
     +      /1X,A3,'-',I2,3X,'<=== CASE STUDY INITIATION DATE.',
     +/10X,'<--- NEW VALUE? (Ex. JUN-15)')
      READ (5,1700,ERR = 1900) RMM,DASH,IDYY
      IF (RMM .EQ. '   ' .AND. IDYY .EQ. 0) GO TO 2200
      IF (DASH .NE. '-' .OR. IDYY .LT. 0 .OR. IDYY .GT. 31) GO TO 1900
      IDUMM = JULIAN(IDYY,RMM,YEAR)
      IF (IDUMM .GT. 366) GO TO 1900
      LWATER = IDUMM
 2200 CONTINUE
 2300 CONTINUE
C-----------------------------------------------------------------------
C     IF (LWATER .GT. IPLTRL) LWATER=IPLTRL
C-----------------------------------------------------------------------
      GO TO 500
 2400 WRITE (*,2500)
 2500 FORMAT(10X,'ERROR! Row spacing must be between 0 and 2 m.')
 2600 PLTPOP = 1. / (SBETN *SROWSP )
      IF (PLTPOP .LT. 1. .OR. PLTPOP .GT. 999.) WRITE (*,2650)
 2650 FORMAT(10X,'ERROR! Plant population must be between 1 and 999',
     $ ' pl/m2.')
      IF (OUTOOP .EQ. 'YES') WRITE (*,2700) SROWSP,PLTPOP,ROWSPC
 2700 FORMAT(1X,F6.3,'m. ','<=== CURRENT ROW SPACING [',F6.2,' PL/M2]',
     +      /1X,F6.3,'m. ','<=== CASE STUDY ROW SPACING ',
     +/10X,'<--- ENTER ROW SPACING IN m.')
      READ (5,2800) LINE
 2800 FORMAT(72A1)
      CALL VERIFY(LINE,RSP,FLAG)
      IF (FLAG .GT. 0) GO TO 2400
      IF (RSP .LT. 0. .OR. RSP .GT. 2.) GO TO 2400
      IF (RSP .GT. 0.) SROWSP = RSP
      PLTPOP = 1. / (SBETN *SROWSP )
      IF (PLTPOP .LT. 1. .OR. PLTPOP .GT. 999.) GO TO 2600
      GO TO 3100
 2900 WRITE (*,3000)
 3000 FORMAT(10X,'ERROR! Intrarow spacing must be between 0 and 2 m.')
 3100 PLTPOP = 1. / (SBETN *SROWSP )
      IF (PLTPOP .LT. 1. .OR. PLTPOP .GT. 999.) WRITE (*,2650)
      IF (OUTOOP .EQ. 'YES') WRITE (*,3200) SBETN,PLTPOP,BETN
 3200 FORMAT(1X,F6.4,'m. ','<=== CURRENT PLANT SPACING [',F6.2,' PL/M2]'
     +      ,/1X,F6.4,'m. ','<=== CASE STUDY PLANT SPACING.',
     +/10X,'<--- ENTER PLANT SPACING IN m.')
      READ (5,2800) LINE
      CALL VERIFY(LINE,BPS,FLAG)
      IF (FLAG .GT. 0) GO TO 2900
      IF (BPS .LT. 0. .OR. BPS .GT. 2.) GO TO 2900
      IF (BPS .GT. 0.) SBETN = BPS
      PLTPOP = 1. / (SBETN *SROWSP )
      IF (PLTPOP .LT. 1. .OR. PLTPOP .GT. 999.) GO TO 3100
      GO TO 500
C-----------------------------------------------------------------------
C
```

```
C-------------------------------------------------------------------------
 3300 IF (OUTOOP .EQ. 'YES') CALL CLEAR
      IF (OUTOOP .EQ. 'YES') WRITE (*,3400)
 3400 FORMAT(1X,'IRRIGATION MANAGEMENT STRATEGY',/1X,34('='),/,
     +/1X,'1) RAINFED.',/1X,
     +'2) IRRIGATE ACCORDING TO THE FIELD SCHEDULE.',/1X,
     +'3) PHASE SPECIFIC AUTO IRRIGATION ON DEPTH & AVAILABLE WATER',
     +/1X,'4) NO WATER STRESS.',/)
 3500 IF (OUTOOP .EQ. 'YES') WRITE (*,3600) IIRRS,IIRR
 3600 FORMAT(1X,I1,']',1X,'<=== SELECTED STRATEGY.',
     +      /1X,I1,']',1X,'<=== CASE STUDY STRATEGY.',
     +/4X,     '<--- ALTERNATE SELECTION? ')
      READ (5,3700,ERR = 3500) NANS
 3700 FORMAT(I1)
      IF (NANS .LT. 0 .OR. NANS .GT. 4) GO TO 3500
      IF (NANS .EQ. 0) GO TO 500
      IF (NANS .NE. 0) IIRRS = NANS
      IF (IIRRS .EQ. 3) GO TO 3800
      GO TO 500
 3800 IF (OUTOOP .EQ. 'YES') CALL CLEAR
      IF (OUTOOP .EQ. 'YES') WRITE (*,3900)
 3900 FORMAT(4X,'AUTOMATIC IRRIGATION BASED ON DEPTH & AVAILABLE WATER'/
     +,' PHASE',4X,'PHASE DESCRIPTION',5X,'SOIL DEPTH',                 '
     +   AVAILABLE WATER',/,                                            '
     +  NO                                        m              %      ',/,  '
     +=================================================================',/)
      IF (OUTOOP .EQ. 'YES') WRITE (*,4000)
     +   (SDSOIL(I),STHETA(I),I = 1,3),SEFFIR
 4000 FORMAT('  0       RETURN TO MENU',//,
     +'  1       PLANTING - FLOWERING   ',2X,F6.3  ,10X,F4.1,/,
     +'  2       FLOWERING- FIRST POD   ',2X,F6.3  ,10X,F4.1,/,
     +'  3       FIRST POD- PHYS. MAT.  ',2X,F6.3  ,10X,F4.1,/,
     +'  4       IRRIGATION EFFICIENCY   ',24X,F4.2,//,
     +'  <---  SELECTION BY NUMBER')
      READ (5,4100,ERR = 3800) MENU
 4100 FORMAT(I2)
      IF (MENU .LT. 0 .OR. MENU .GT. 4) GO TO 3800
      IF (MENU .EQ. 0) GO TO 500
      IF (MENU .EQ. 4) GO TO 4400
 4200 IF (OUTOOP .EQ. 'YES') WRITE (*,4300)
 4300 FORMAT(' INPUT DEPTH & AVAILABLE WATER. Separate numbers with',
     +/' a "comma". [ Ex. 0.5,70.0  Note: Decimal point is a MUST! ')
      READ (5,*,ERR = 4200) D,D1
      IF (D1 .LE. 0 .OR. D1 .GT. 100) GO TO 4200
      IF (D .LE. 0) GO TO 4200
      SDSOIL(MENU) = D
      STHETA(MENU) = D1
      GO TO 3800
 4400 IF (OUTOOP .EQ. 'YES') WRITE (*,4500) SEFFIR
 4500 FORMAT(1X,F4.2,5X,'<=== IRRIGATION EFFICIENCY.',
     +/10X,'<--- NEW VALUE? ')
      READ (5,2800) LINE
      CALL VERIFY(LINE,EFF,FLAG)
      IF (FLAG .GT. 0) GO TO 4400
```

```
      IF (EFF .LT. 0. .OR. EFF .GT. 1) GO TO 4400
      IF (EFF .GT. 0) SEFFIR = EFF
      GO TO 3800
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
 4600 CALL IPSOIL
      GO TO 500
 4700 CALL IDWTH
      GO TO 500
 4750 CALL IPCERC
      GO TO 500
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
 4800 CONTINUE
      NDX1   = 0
      RETURN
      END
```

Filename: IPTRT.FOR

```
$STORAGE:2
      SUBROUTINE IPTRT
C-------------------------------------------------------------------------
C
C-------------------------------------------------------------------------
$INCLUDE: 'COMGRO.DAT'
$INCLUDE: 'COMIO.DAT'
$INCLUDE: 'COMSOI.DAT'
C-------------------------------------------------------------------------
C
C-------------------------------------------------------------------------
      INTEGER TRTNO
      CALL PHINIT
      NVALPH(1) = 1
      IF (IPHN .EQ. 0) GO TO 200
           DO 100 JPX = 1,11
           NSETPH(JPX+1) = 1
           NVALPH(JPX+1) = JULPHN(JPX) +(IPLT - IWATER)
  100      CONTINUE
  200 CONTINUE
      NAP = 1
      IF (IIRR .NE. 2 ) GO TO 1200
      OPEN (16,FILE = FILE6,STATUS = 'OLD')
  300 READ (16,*,END = 700,ERR = 900) TRTNO
      IF (TRTNO .EQ. NTRT) GO TO 500
  400 READ (16,*,END = 700,ERR = 900) JULAPL(NAP)
      IF (JULAPL(NAP) .GT. 0) GO TO 400
      GO TO 300
  500 CONTINUE
  600 READ (16,*,END = 700,ERR = 900) JULAPL(NAP),AMIR(NAP)
      IF (JULAPL(NAP) .LE. 0) GO TO 1100
      IF (JULAPL(NAP) .LT. JULAPL(1)) JULAPL(NAP) = JULCHK+JULAPL(NAP)
      IF (JULAPL(NAP) .LT. IWATER) GO TO 600
      NAP = NAP + 1
      GO TO 600
  700 WRITE (*,800) NTRT,FILE6
  800 FORMAT(/10X,'Data on treatment ',I3,' missing in ',
     +A12,' . PRESS <Cntrl-Break> keys, and fix the problem.')
      READ (5,1900) ANS
      GO TO 1100
  900 WRITE (*,1000) FILE6
 1000 FORMAT(/10X,'OOPS! Format data miss-match in file: ',A12,/10X,
     +     'PRESS <Ctrl-Break> keys, and fix the problem.')
      READ (5,1900) ANS
      GO TO 1100
 1100 CLOSE (16)
 1200 CONTINUE
      NAP = NAP - 1
C-------------------------------------------------------------------------
C
C-------------------------------------------------------------------------
      OPEN (8,FILE = FILEA,STATUS = 'OLD')
```

```
 1300 READ (8,1400,ERR = 1700,END = 1500) TRTNO,XSDYLD,XSDWT,XSDSM,XSPP,
     +     XLAIR4,XBIOM,XSTALK,IFLRJD,MATJD,IFFSP,IFFS,XPDYLD,XPCMAT
 1400 FORMAT(9X,I2,1X,F7.0,1X,F7.4,1X,F6.0,1X,F4.0,1X,F5.2,2(1X,F6.0),
     +     2(1X,I3),/,2(1X,I3),1X,F7.0,1X,F6.2)
      XTHRES = 0.0
      IF (XPDYLD .GT. 0.0 .AND. XSDYLD .GT. 0.0) XTHRES =
     $  XSDYLD*100./XPDYLD
      XHI = 0.0
      IF (XBIOM .GT. 0.0 .AND. XPDYLD .GT. 0.0) XHI = XPDYLD/XBIOM
      IF (TRTNO .EQ. NTRT) GO TO 1800
      GO TO 1300
 1500 WRITE (*,1600) NTRT,FILEA
 1600 FORMAT(/,' OOPS! Treatment ',I3,' not found in file :',A12,
     +     /T8, 'PRESS <Ctrl-Break> keys, and fix the problem.')
      READ (5,1900) ANS
      GO TO 1800
 1700 WRITE (*,1000) FILEA
      READ (5,1900) ANS
 1800 CLOSE (8)
 1900 FORMAT(1A1)
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
      CALL IPSOIL
      CALL IPVAR
      CALL IPCERC
      CALL PHOTIN
      CALL VARTY
      CALL ROOTS
      CALL IDWTH
      RETURN
      END
```

Filename: OPSEAS.FOR

```
$STORAGE:2
      SUBROUTINE OPSEAS
$INCLUDE: 'COMGRO.DAT'
$INCLUDE: 'COMIO.DAT'
$INCLUDE: 'COMSOI.DAT'
$INCLUDE: 'COMDIS.DAT'
C-----------------------------------------------------------------------
C
C
C THIS SUBROUTINE GENERATES OUTPUT FOR SEASONAL SIMULATED
C
C-----------------------------------------------------------------------
      CHARACTER*3  RMM
      CHARACTER*10 STAGE
C-----------------------------------------------------------------------
C
C
C INITIALIZE COUNTERS, AVERAGES
C
C-----------------------------------------------------------------------
      IF (N .EQ. 1) THEN
      DSTRES = 0.
      STRESP = 0.
      STRESS = 0.
      CWSV = 0.0
      CWSR = 0.0
C-----------------------------------------------------------------------
C
C
C   THE FOLLOWING GENERATES HEADING FOR OUTPUT FILE
C
C
C-----------------------------------------------------------------------
      IF (OUT2OP .EQ. 'YES') THEN
      IF (NREP .EQ. 1) WRITE (NOUT2,100)
  100 FORMAT(31X,'PNUTGRO V1.02',/,31X,13('='),/)
      WRITE (NOUT2,200) NREP,TITLER
      WRITE (NOUT2,300) INSTE,SITEE,EXPTNO,YEAR,NTRT,TITLEE,TITLET,
     +     TITLEW,TAXON,VRNAME,IVRGRP
      ENDIF
      IF (OUT3OP .EQ. 'YES') THEN
      IF (NREP .EQ. 1) WRITE (NOUT3,100)
      WRITE (NOUT3,200) NREP,TITLER
      WRITE (NOUT3,300) INSTE,SITEE,EXPTNO,YEAR,NTRT,TITLEE,TITLET,
     +     TITLEW,TAXON,VRNAME,IVRGRP
      ENDIF
      IF (OUT6OP .EQ. 'YES') THEN
      IF (NREP .EQ. 1) WRITE (NOUT6,100)
      WRITE (NOUT6,200) NREP,TITLER
      WRITE (NOUT6,300) INSTE,SITEE,EXPTNO,YEAR,NTRT,TITLEE,TITLET,
     +     TITLEW,TAXON,VRNAME,IVRGRP
      ENDIF
```

```
  200 FORMAT(/1X,'RUN ',I3,7X,A40)
  300 FORMAT (1X,'INST_ID: ',A2,2X,'SITE_ID: ',A2,2X,'EXPT_NO: ',
     +A2,2X,'YEAR: 19',I2,2X,'TRT_NO: ',I2,/,
     +1X,'EXPERIMENT',3X,': ',A40,/1X,'TREATMENT',4X,': ',A40,/,
     +1X,'WEATHER SET',2X,': ',A40,/,
     +1X,'SOIL TYPE',4X,': ',A60,/,
     +1X,'VARIETY'6X,': ',A16,2X,'MATURITY : ',I2)
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
      IF (OUT2OP .EQ. 'YES') THEN
      GO TO (400,600,800,1000),IIRR
  400 WRITE (NOUT2,500)
  500 FORMAT (1X,'IRRIGATION',3X,': ','RAINFED')
      GO TO 1200
  600 WRITE (NOUT2,700)
  700 FORMAT(1X,'IRRIGATION',3X,': ','ACCORDING TO THE FIELD SCHEDULE')
      GO TO 1200
  800 WRITE (NOUT2,900) (SDSOIL(I),STHETA(I),I = 1,3)
  900 FORMAT(1X,'IRRIG.  :AUTO-> R1[',F4.2,'m,'1X,F3.0,
     +                           '%] FIRST POD[',F4.2,'m,'1X,F3.0,
     +                           '%] R7[',F4.2,'m,'1X,F3.0,'%]')
      GO TO 1200
 1000 WRITE (NOUT2,1100)
 1100 FORMAT(1X,'IRRIGATION',3X,': ','NO WATER STRESS')
 1200 IF (IIRR .NE. 3) GO TO 1400
      WRITE (NOUT2,1300) AMTMIN
 1300 FORMAT(10X,'NOTE: no irrigation if demand is less',
     +' than ',F5.2,'mm')
 1400 CONTINUE
      ENDIF
      IF (OUT3OP .EQ. 'YES') THEN
      GO TO (1500,1600,1700,1800),IIRR
 1500 WRITE (NOUT3,500)
      GO TO 1900
 1600 WRITE (NOUT3,700)
      GO TO 1900
 1700 WRITE (NOUT3,900) (SDSOIL(I),STHETA(I),I = 1,3)
      GO TO 1900
 1800 WRITE (NOUT3,1100)
 1900 IF (IIRR .NE. 3) GO TO 2000
      WRITE (NOUT3,1300) AMTMIN
 2000 CONTINUE
      ENDIF
      IF (OUT6OP .EQ. 'YES') THEN
      GO TO (2010,2020,2030,2040),IIRR
 2010 WRITE (NOUT6,500)
      GO TO 2050
 2020 WRITE (NOUT6,700)
      GO TO 2050
 2030 WRITE (NOUT6,900) (SDSOIL(I),STHETAC(I),I = 1,3)
      GO TO 2050
 2040 WRITE (NOUT6,1100)
 2050 IF (IIRR .NE. 3) GO TO 2060
```

```
      WRITE (NOUT6,1300) AMTMIN
 2060 CONTINUE
      ENDIF
      IF (OUT3OP .EQ. 'YES') THEN
      WRITE (NOUT3,2100)
 2100 FORMAT (1H ,/,1X,'JUL',2X,13('-'),' AVERAGE ',14('-'),1X,
     +  '    PERIOD',18X,'SOIL WATER CONTENT W/DEPTH',10X,'TOTAL',/,
     +  ' DAY  EP   ET   EO   SR  HLIGHT  MAX   MIN   RAIN  IRRIG',
     +  '     SW1   SW2   SW3   SW4   SW5   SW6   SW7   SW8  PESW',/)
      ENDIF
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
      IF (OUT2OP .EQ. 'YES') THEN
      WRITE (NOUT2,2200)
 2200 FORMAT (1H ,/,' JUL  VST-   LAI    PODS    STEM    SEED    LEAF',
     +  3X,'CANO-     POD   SHELL    ROOT    SEED HARVEST SHELL SLA',
     +  4X,'SEED  NIT  WATER ', 13X,'ROOT LENGTH DENSITY',/,
     +  1X,'DAY  AGE',13X,'NO',7(6X,'WT'),6X,
     +  'NO',3X,'IND',5X,'%',10X,'SIZE',3X,'%',2X,'STRESS',
     +  4X,'L1   L2   L3   L4   L5   L6   L7   L8',/)
      ENDIF
      IF (OUT6OP .EQ. 'YES') THEN
      WRITE (NOUT6,2210)
 2210 FORMAT (1H ,/,' JUL  LAI  % INF  % DIS  % DEF  % DIS',1X,
     +  'CONID DENS S-SPOR F-SPOR INFECT C-TEMP  TOT-LA  INF-LA',2X,
     +  'DIS-LA  LAT-LA  PRE-LA  SPO-LA  POS-LA  COH-14  COH-28',2X,
     +  'COH-42  COH-56  COH-70  COH-84  COH-98',/,
     +  1X,'DAY',8X,'AREA',2(3X,'AREA'),2X,'SEVER (#x100000)',
     +  4(1X,'FACTOR'),4X,'dm2',4(5X,'dm2'),9(5X,'cm2'),/)
      ENDIF
      ENDIF
C-----------------------------------------------------------------------
C
C  THE FOLLOWING GENERATES OUTPUT FOR FILE OUT3
C
C-----------------------------------------------------------------------
      IF (OUT3OP .EQ. 'YES') THEN
      IF (N .EQ. 1 .OR. N .EQ. NR8) GO TO 2300
      IF (N/KOUTWA*KOUTWA .NE. N) GO TO 2500
 2300 WRITE (NOUT3,2400) JUL,EP,ET,EO,SRAD,HLIGHT,TMAX,TMIN,CRAIN,TOTIR,
     +     SW(1),SW(2),SW(3),SW(4),SW(5),SW(6),SW(7),SW(8),PESW* 10.0
 2400 FORMAT (I4,F4.1,2F5.1,2F6.2,2F6.1,1X,2(F6.1,1X),8(1X,F5.3),
     + 2X,F5.1)
      ENDIF
C-----------------------------------------------------------------------
C
C THE FOLLOWING GENERATES OUTPUT FOR OUT2
C
C-----------------------------------------------------------------------
 2500 IF (OUT2OP .EQ. 'YES') THEN
      IF (N+IWATER-1 .EQ. IPLT .OR. N .EQ. NR8) GO TO 2600
      IF (IWATER+N-1 .LT. IPLT ) GO TO 2710
      IF (N/KOUTGR*KOUTGR .NE. N) GO TO 2710
```

```
 2600 CONTINUE
      SHELPC = 0.0
      IF (PODWT .GT. 0.1) SHELPC = SDWT*100./PODWT
      SHELLW = PODWT - SDWT
      SDSIZE = 0.0
      IF (SEEDNO .GT. 0.0) SDSIZE = SDWT/SEEDNO*1000
      HI = 0.
      IF (TOPWT .GT. 0. .AND. PODWT .GE. 0.) HI = PODWT/TOPWT
      WRITE (NOUT2,2700) JUL,VSTAGE,XLAI,PODNO,STMWT*10.,SDWT*10.,WTLF*
     +     10.,TOPWT*10.,PODWT*10.,SHELLW*10,RTWT*10,SEEDNO,HI,
     +     SHELPC,SLA,SDSIZE,PCNIT,TURFAC,RLV(1),RLV(2),
     +     RLV(3),RLV(4),RLV(5),RLV(6),RLV(7),RLV(8)
 2700 FORMAT (I4,1X,F5.2,1X,F5.2,1X,9(F7.1,1X),F5.3,1X,
     +       F5.1,1X,F6.1,1X,F6.1,1X,2(F5.2,1X),8F5.2)
      ENDIF
C-----------------------------------------------------------------------
C
C THE FOLLOWING GENERATES OUTPUT FOR OUT6
C
C-----------------------------------------------------------------------
 2710 IF (OUT6OP .EQ. 'YES') THEN
      IF (N .EQ. 1 .OR. N .EQ. NR8) GO TO 2720
      IF (N/KOUTDS*KOUTDS .NE. N) GO TO 2800
 2720 WRITE (NOUT6,2730) JUL,XLAI,PERINF,PERDIS,PERDEF,DSEVER,CINDEX,
     +     SCOAIR,FCOAIR,XINDEX,CTEMFC,GTOTLA,GINFLA,GDISLA,GLATLA,
     +     GPRELA,GSPOLA,GPOSLA,TOTLA1,TOTLA2,TOTLA3,TOTLA4,TOTLA5,
     +     TOTLA6,TOTLA7
 2730 FORMAT (I4,F5.2,4F7.2,1X,E10.4,4F7.4,14F8.1)
      ENDIF
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
 2800 DSTRES = DSTRES + 1.
      STRESS = STRESS + TURFAC
      STRESP = STRESP + SWFAC
      IF ( N .GT. NVEGO .AND. N .LE. NPODO) CWSV = CWSV + SWFAC
      IF ( N .GT. NPODO .AND. N .LE. NR7) CWSR = CWSR + SWFAC
      IF (DSTRES .GE. 1) ASTRES = 1. - (STRESS/DSTRES)
      IF (DSTRES .GE. 1) PSTRES = 1. - (STRESP/DSTRES)
C-----------------------------------------------------------------------
C
C     WRITE TO OUT1 OUTPUT FILE AT DEFINED PHENOLOGICAL STAGES
C
C-----------------------------------------------------------------------
      IF (IWATER+N-1 .EQ. IPLT) THEN
      IF (OUTOOP .EQ. 'YES') WRITE (*,2900)
 2900 FORMAT(40X,' Press < ENTER > key to continue ',2X,\)
      READ (5,3000) ANS
 3000 FORMAT(1A1)
      IF (OUTOOP .EQ. 'YES') CALL CLEAR
      IF (OUTOOP .EQ. 'YES') WRITE (*,3100) NREP,INSTE,SITEE,
     $  YEAR,TITLER
 3100 FORMAT(/3X,'RUN NO. ',I3,8X,'SIMULATION OUTPUT',//,3X,A2,2X,
     +A2,2X,'19',I2,7X,A40,//42X,'DIS   H2O BAL COMPONENTS    DROUGHT')
```

```
      IF (OUTOOP .EQ. 'YES') WRITE (*,3200)
 3200 FORMAT (3X,'DATE',1X,'CROP',1X,'GROWTH',3X,'BIOMASS',2X,' LAI ',
     +'  VC  ','SEV ',' EP  ',' ET  ',' RAIN ','IRRIG ','  STRESS',
     +/,9X,'AGE',1X,'STAGE',6X,'KG/HA',7X,'STAGE',1X,
     + ' %   mm    mm     mm     mm  PHOTO TURGOR',/,1X,79('-'))
      IF (OUT1OP .EQ. 'YES') THEN
      WRITE (NOUT1,3100) NREP,INSTE,SITEE,YEAR,TITLER
      WRITE (NOUT1,3200)
      ENDIF
      ENDIF
           DO 4700 I = 1,12
           GO TO (3300,3400,3500,3600,3700,3800,3900,4000,4100,4200,
     +          4300,4400),I
 3300      IF (N .NE. (IPLT-IWATER+1)) GO TO 4700
           STAGE = 'SOWING    '
           GO TO 4500
 3400      IF (N .NE. NVEG0) GO TO 4700
           STAGE = 'EMERGENCE '
           GO TO 4500
 3500      IF (N .NE. NVEG1) GO TO 4700
           STAGE = 'V1 STAGE  '
           GO TO 4500
 3600      IF (N .NE. NR1) GO TO 4700
           STAGE = 'FLOWERING '
           GO TO 4500
 3700      IF (N .NE. NPOD0) GO TO 4700
           STAGE = 'R2 STAGE  '
           GO TO 4500
 3800      IF (N .NE. NR3) GO TO 4700
           STAGE = 'R3 STAGE  '
           GO TO 4500
 3900      IF (N .NE. NR4) GO TO 4700
           STAGE = 'R4 STAGE '
           GO TO 4500
 4000      IF (N .NE. NR6) GO TO 4700
           STAGE = 'R6 STAGE  '
           GO TO 4500
 4100      IF (N .NE. NDLEAF) GO TO 4700
           STAGE = 'END LEAF  '
           GO TO 4500
 4200      IF (N .NE. NDSET) GO TO 4700
           STAGE = 'END POD   '
           GO TO 4500
 4300      IF (N .NE. NR7) GO TO 4700
           STAGE = 'PHYS. MAT '
           GO TO 4500
 4400      IF (N .NE. NR8) GO TO 4700
           STAGE = 'HARV. MAT '
 4500      CONTINUE
           DSTRES  = 0.
           STRESS  = 0.
           STRESP  = 0.
C-------------------------------------------------------------------------------
C
```

```
C** IAGE is days after planting, IAGE = 0 on day of planting
C
C-----------------------------------------------------------------------
          IAGE = N + IWATER - IPLT - 1
          IPYEAR  = YEAR
          IF (IPLT .GT. JULCHK) IPYEAR = YEAR+1
          CALL NAILUJ(JUL,IPYEAR,RMM,IPX)
          IF (OUTOOP .EQ. 'YES') WRITE (*,4600) RMM,IPX,IAGE,STAGE,
     +       TOPWT*10.,XLAI,VSTAGE,DSEVER,CEP,CET,CRAIN,TOTIR,PSTRES,
     +       ASTRES
          IF (OUT1OP .EQ. 'YES') THEN
          WRITE (NOUT1,4600) RMM,IPX,IAGE,STAGE,TOPWT*10.,XLAI,VSTAGE,
     +          DSEVER,CEP,CET,CRAIN,TOTIR,PSTRES,ASTRES
 4600   FORMAT (1X,A3,1X,I2,2X,I3,1X,A10,F6.0,
     +  1X,F5.2,1X,F4.1,3(F5.0),2F6.0,2(1X,F5.3))
          ENDIF
 4700     CONTINUE
      RETURN
      END
```

Filename: PODS.FOR

```
$STORAGE:2
      SUBROUTINE PODS
$INCLUDE: 'COMGRO.DAT'
$INCLUDE: 'COMSOI.DAT'
$INCLUDE: 'COMIO.DAT'
$INCLUDE: 'COMDIS.DAT'
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
      DIMENSION PHTIM(365),SDNO(200),WTSD(200),SHELN(200),WTSHE(200),
     +SUPDE(200),AVTEM(200)
      DATA PHTIM/365*0.0/
      PGSD = 0.0
      PGSHEL = 0.0
      WSHDOT = 0.0
      ALPHA = 1.0
      WSDDOT = 0.0
      IF (N .GT. NVEGO+1) GO TO 200
C-----------------------------------------------------------------------
C
C     INITIALIZE PLANT VARIABLES AT EMERGENCE
C
C-----------------------------------------------------------------------
      XFRT = XFRUIT
      XMLMAX = BETAL * WTLF
      XMSMAX = BETAS * STMWT
      XMRMAX = BETAR * RTWT
      XMSHMX = 0.0
      WTABRT = 0.0
      WTSHM = 0.0
      WTSHMT = 0.0
      SHMINE = 0.0
      TEMPOD = 1.0
      SWBAR = 1.0
      TURXFR = 0.0
      SWADD1 = 1.0
      SWADD2 = 1.0
      ACCAGE = 0.0
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
          DO 100 NPP = 1,200
          SHELN(NPP) = 0.0
          WTSHE(NPP) = 0.0
          WTSD(NPP) = 0.0
          SDNO(NPP) = 0.0
  100     CONTINUE
      GO TO 2700
  200 CONTINUE
C-----------------------------------------------------------------------
C     EFFECT OF SOIL WATER IN TOPSOIL ON POD ADDITION
C-----------------------------------------------------------------------
```

```
      ACTSW = 0.0
      POTSW = 0.0
      DSW = 0.0
           DO 300 I = 1,NLAYR
           DSW = DSW + DLAYR(I)
           FLAYR = 1.0
           IF (DSW .GT. DSWBAR) FLAYR = (DSWBAR-(DSW-DLAYR(I)))/DLAYR(I)
           ACTSW = ACTSW + (SW(I) - LL(I)) * DLAYR(I) * FLAYR
           POTSW = POTSW + (DUL(I) - LL(I)) * DLAYR(I) * FLAYR
           IF ( FLAYR .LT. 1.0 ) GO TO 400
  300      CONTINUE
  400 SWBAR = ACTSW / POTSW
      SWBAR = AMIN1 (SWBAR,1.0)
      SWBAR = AMAX1 (SWBAR,0.0)
      SWADD1 = TABEX (YSWBAR,XSWBAR,SWBAR,NSWBAR)
      SWADD2 = TABEX (YSWFAC,XSWFAC,SWFAC,NSWFAC)
C-----------------------------------------------------------------------
C
C
C     TEMPERATURE EFFECT ON PARTITIONING TO PODS
C     DIFFERENT FROM TEMPERATURE EFFECT ON POD ADDITION OR ON SEED
C     OR SHELL GROWTH RATES.  HIGH TEMP WOULD INCREASE FRACTION TO VEG
C
C-----------------------------------------------------------------------
      TEMXFR = 0.
           DO 500 I = 1,24
           TEMXFR = TEMXFR + TABEX(YXFTEM,XXFTEM,THR(I),NXFTEM)
  500      CONTINUE
      TEMXFR = TEMXFR/24.
C-----------------------------------------------------------------------
C
C     PARTITIONING TO PODS IS INCREASED (AND THAT TO VEGETATION IS
C     DECREASED) AS THE RATIO OF POTENTIAL ROOT WATER UPTAKE TO
C     EVAPORATIVE DEMAND IS DECREASED.  IN ADDITION, POD ADDITION
C     IS REDUCED BY LOW WATER IN THE FRUITING ZONE (SWBAR) OR
C     BY LACK OF PHOTOSYNTHATE (SWFAC).
C
C-----------------------------------------------------------------------
      TURXFR = XFRMAX * EXP(-TURSEN * AMAX1((TURXPR-TURTHR),0.0))
      TURXFR = AMIN1 ((1.-XFRT),TURXFR)
      TURXFR = AMAX1 (0.0,TURXFR)
C-----------------------------------------------------------------------
C
C     PRESENTLY ASSUME NIGHTLENGTH AND TEMPERATURE ARE MULTIPLICATIVE
C     BUT THAT TURGOR EFFECT ADDS TO THE PARTITIONING
C
C-----------------------------------------------------------------------
      XFRUIT = XFRT * RNIT * TEMXFR + XFRT * TURXFR
      XFRUIT = AMIN1(XFRUIT,1.0)
      XFRUIT = AMAX1(XFRUIT,0.0)
C-----------------------------------------------------------------------
C
C-----------------------------------------------------------------------
      IF (N .LT. NPOD0) GO TO 2700
```

```
      IF (N .EQ. NPOD0) PHTIM(1) = 0.0
      IF (N .EQ. NPOD0) GO TO 600
      PHTIM(N-NPOD0+1) = PHTIM(N-NPOD0) + DTX
  600 CONTINUE
C-----------------------------------------------------------------------
C
C     CALCULATE MAXIMUM GROWTH RATE FOR ALL SEEDS/M**2 AS A FUNCTION
C     OF TEMPERATURE, INSECT FEEDING AND PUNCTURE DAMAGE.
C
C-----------------------------------------------------------------------
      REDPUN = 1.0
      TMPFAC = CONSD1 + CONSD2 * TAVG + CONSD3 * TAVG**2
      SDGR = SDMAXR * TMPFAC / 1000.
      IF (PUNCSD .LE. 0.001) GO TO 700
      REDPUN = REDPUN - (PUNCTR/PUNCSD) * RPRPUN
      REDPUN = AMAX1(0.0,REDPUN)
  700 CONTINUE
C-----------------------------------------------------------------------
C
C     COMPUTE CARBOHYDRATE DEMAND, DWPMAX
C
C-----------------------------------------------------------------------
      DWPMAX = 0.0
C-----------------------------------------------------------------------
C     REMEMBER YESTERDAYS MATURE SHELL WT.
C-----------------------------------------------------------------------
      WTSHMY = WTSHM
      WTSHM = 0.0
            DO 800 NPP = 1, N-NPOD0
C-----------------------------------------------------------------------
C
C     COMPUTE PHYSIOL AGE OF COHORT
C
C-----------------------------------------------------------------------
            PAGE = PHTIM(N-NPOD0+1) - PHTIM(NPP)
C-----------------------------------------------------------------------
C
C     DO NOT ALLOW SEED TO GROW UNTIL SHELS ARE GREATER THAN LAGSD
C     PHYSIOL AGE.  SHOULD BE PHOTOPERIOD EFFECT IN SOYBEAN.
C
C-----------------------------------------------------------------------
            IF (PAGE .LT. LAGSD) GO TO 800
C-----------------------------------------------------------------------
C
C     PREVENT COHORT FROM EXCEEDING THRESHING LIMIT
C
C-----------------------------------------------------------------------
            SDMAX = WTSHE(NPP) * THRESH/(100. - THRESH) - WTSD(NPP)
            SDMAX = AMAX1(0.0,SDMAX)
C-----------------------------------------------------------------------
C     COMPUTE SHELL WT OF COHORTS THAT ARE FULL
C-----------------------------------------------------------------------
            IF (SDMAX .LE. 0.0) WTSHM = WTSHM + WTSHE(NPP)
C-----------------------------------------------------------------------
```

```
C      NEED TO ADD PUNCTURED SEED EFFECT LATER
C
C-----------------------------------------------------------------------
            DWPMAX = DWPMAX + AMIN1(SDGR*SDNO(NPP),SDMAX)
  800       CONTINUE
C-----------------------------------------------------------------------
C     COMPUTE COHORTS OF SHELL WT. THAT REACH THRESH TODAY
C-----------------------------------------------------------------------
      WTSHMT = WTSHM - WTSHMY
C-----------------------------------------------------------------------
C   THIS SECTION SAVES THE MAX VALUE OF THE LEAF, STEM, ROOT, AND
C   SHELL PROTEIN POOLS AT THE END OF YESTERDAY AND SUBTRACTS ANY
C   AVAILABLE PROTEIN LOSS DUE TO YESTERDAYS DROUGHT, INSECT OR DISEASE
C   LOSS OF TISSUE WHICH THUS CAN NOT MOBILIZE ITS AVAILABLE PROTEIN.
C
C-----------------------------------------------------------------------
      IF (XMS .GT. XMSMAX) XMSMAX = XMS
      IF (XML .GT. XMLMAX) XMLMAX = XML
      IF (XMSH .GT. XMSHMX) XMSHMX = XMSH
      IF (XMR .GT. XMRMAX) XMRMAX = XMR
      XMLMAX = XMLMAX - GAMMAL * (SLNDOT + WLIDOT + WLCDOT)
        XMLMAX = AMAX1(0, XMLMAX)
      XMSMAX = XMSMAX - GAMMAS * (SSNDOT + WSCDOT)
        XMSMAX = AMAX1(0, XMSMAX)
      XMRMAX = XMRMAX - GAMMAR * SRDOT
        XMRMAX = AMAX1(0, XMRMAX)
      XMSHMX = XMSHMX - GAMMSH * (WTABRT + WTSHMT)
        XMSHMX = AMAX1(0, XMSHMX)
      XMLRTE = WTLF * 0.015
C-----------------------------------------------------------------------
C      CHANGED JUNE 9, 1985 BY K. J. BOOTE TO MIMIC PEANUT N MOBILIZ
C     CALCULATION TO ESTIMATE RATE OF NITROGEN MINING, USING DTX
C     AND A RELATIVE RATE PER PHYSIOLOGICAL DAY (CNMOB) TO ACHIEVE
C     2.85 % N BY HARVEST MATURITY.
C
C-----------------------------------------------------------------------
      DX = DTX*CNMOB
C-----------------------------------------------------------------------
C     **** POTENTIAL N MINING RATE/DAY, G PROTEIN/M2-DAY
C-----------------------------------------------------------------------
      XMSPOS = XMSMAX * DX
      XMLPOS = XMLMAX * DX
      XMSHPS = XMSHMX * DX
      XMRPOS = XMRMAX * DX
      XMLDOT = AMIN1(XMLPOS,XML,XMLRTE)
      XMSDOT = AMIN1(XMSPOS,XMS)
      XMSHDT = AMIN1(XMSHPS,XMSH)
      XMRDOT = AMIN1(XMRPOS,XMR - GAMMAR * SRDOT)
      XMTDOT = XMSHDT+XMLDOT+XMSDOT+XMRDOT
C-----------------------------------------------------------------------
C
C     THIS SECTION CALCULATES SEED GROWTH
C
C     **** CALCULATE MAXIMUM SEED GROWTH RATE USING MINED N
```

```
C-----------------------------------------------------------------------
      WSDDOT = AMIN1(XFRUIT*PGNET/AGRSD2,XMTDOT/SDPRO)
C-----------------------------------------------------------------------
C     **** REDUCE GROWTH RATE IF SEED DEMAND IS LOW
C-----------------------------------------------------------------------
      IF (WSDDOT .GE. DWPMAX) WSDDOT = DWPMAX
C-----------------------------------------------------------------------
C     **** IF XFRUIT*PGNET WAS TOO LOW TO ALLOW ALL OF AVAILABLE PROTEIN
C     BE USED TO MAKE SEED THEN
C     **** ALLOW EXCESS PROTEIN TO BE USED FOR ENERGY, ETC IN MAKING SEE
C-----------------------------------------------------------------------
      PROLFT = XMTDOT - WSDDOT * SDPRO
      WSDBRN = AMIN1(DWPMAX-WSDDOT,PROLFT*ALPHBR)
C-----------------------------------------------------------------------
C     **** CALCULATE ACTUAL DECREASE IN N POOLS, PROPORTIONATELY
C     DECREASE MINING IF SEED IS NOT AVAILABLE TO USE ALL THE MINED N
C-----------------------------------------------------------------------
      XMRAT = 1.0
      IF (XMTDOT .GT. 0.) XMRAT = (WSDDOT*SDPRO+WSDBRN/ALPHBR)/XMTDOT
      XMSHDT = AMIN1(XMRAT*XMSHDT,XMSHDT)
      XMLDOT = AMIN1(XMRAT*XMLDOT,XMLDOT)
      XMSDOT = AMIN1(XMRAT*XMSDOT,XMSDOT)
      XMRDOT = AMIN1(XMRAT*XMRDOT,XMRDOT)
      XMTDOT = AMIN1(XMRAT*XMTDOT,XMTDOT)
      IF (XMTDOT .LE. 0.0001) GO TO 900
C-----------------------------------------------------------------------
C     **** ALPHA IS ALL SEED WEIGHT MADE FROM MINED N / TOTAL MINED N
C-----------------------------------------------------------------------
      ALPHA = (WSDBRN+WSDDOT*SDPRO) / XMTDOT
  900 CONTINUE
      PGSD = WSDDOT * AGRSD2
      WSDDOT = WSDDOT + WSDBRN
      IF (PGSD .GE. XFRUIT*PGNET) GO TO 1100
C-----------------------------------------------------------------------
C     **** MAKE SEED FROM CH2O AT RATE AGRSD1 G CH2O/G SEED WITHOUT MINE
C-----------------------------------------------------------------------
      WSDDOT = (XFRUIT*PGNET - PGSD) / AGRSD1 + WSDDOT
      IF (WSDDOT .GT. DWPMAX) GO TO 1000
      PGSD = XFRUIT*PGNET
      GO TO 1100
C-----------------------------------------------------------------------
C     **** LIMIT WSDDOT AND PGSD IF HAVE EXCEEDED DEMAND BY USING ALL PG
C-----------------------------------------------------------------------
 1000 PGSD = PGSD + (DWPMAX - PGSD/AGRSD2 - WSDBRN) * AGRSD1
      WSDDOT = DWPMAX
 1100 CONTINUE
C-----------------------------------------------------------------------
C
C      CALCULATE RATIO OF SUPPLY TO DEMAND FOR SEED GROWTH (RSD)
C
C-----------------------------------------------------------------------
      RSD = 1.0
      IF (DWPMAX .GT. 0.0001) RSD = AMIN1(WSDDOT/DWPMAX,1.0)
C-----------------------------------------------------------------------
```

```
C
C     GROW SEED COHORTS, GROW BULK SEEDS AS BEFORE IN CROP
C     OLDEST SEEDS HAVE PRIORITY FOR GROWTH
C
C-----------------------------------------------------------------------
      WTSDGR = WSDDOT
           DO 1200 NPP = 1, N-NPODO
           PAGE = PHTIM(N-NPODO+1) - PHTIM(NPP)
           IF (PAGE .LT. LAGSD) GO TO 1200
           SDMAX = WTSHE(NPP) * THRESH/(100. - THRESH) - WTSD(NPP)
           SDMAX = AMAX1(0.0,SDMAX)
           WTSD(NPP) = WTSD(NPP) + AMIN1(SDGR*SDNO(NPP),SDMAX,WTSDGR)
           WTSDGR = WTSDGR - AMIN1(SDGR*SDNO(NPP),SDMAX,WTSDGR)
           IF (WTSDGR .LE. 0.0 ) GO TO 1300
 1200      CONTINUE
 1300 CONTINUE
C-----------------------------------------------------------------------
C
C     THIS SECTION CALCULATES SHELL DEMAND AND  SHELL GROWTH
C     BETWEEN BEGIN PODSTART AND MATURITY
C
C-----------------------------------------------------------------------
      PGLEFT = AMAX1(0.0,(AMIN1(XFRUIT+0.02,1.0)*PGNET - PGSD))
      GRRAT1 = SHMAXR * TMPFAC / 1000.
      IF (N .EQ. NPODO) GO TO 2300
           DO 2100 NPP = 1,N-NPODO
           NAGE = N - NPODO + 1 -NPP
           PAGE = PHTIM(N-NPODO+1) - PHTIM(NPP)
           ADDSHL = 0.0
           SUPDAY = 1.0
           IF (PAGE .LE. LNGSH) GO TO 1400
           IF (PAGE .GT. 40.0) GO TO 1800
           IF (SHELN(NPP) .LT. 0.001) GO TO 2000
           ADDSHL = AMIN1(PGLEFT/AGRSH,GRRAT1*SHTHIC*SHELN(NPP))
           GO TO 1800
 1400      CONTINUE
           IF (PAGE .GT. LNGSH) GO TO 2000
           IF (SHELN(NPP) .LT. 0.001 .OR. GRRAT1 .LT. 0.001) GO TO 2000
           IF (PAGE .LE. LNGPEG) GO TO 1500
           ADDSHL = AMIN1(PGLEFT/AGRSH,GRRAT1 * SHELN(NPP))
           SUPDAY = AMIN1((PGLEFT/AGRSH)/(GRRAT1*SHELN(NPP)),SWADD1)
           IF (SUPDAY .GE. 1.0) SUPDAY = 1.0
           GO TO 1600
 1500      CONTINUE
           ADDSHL = AMIN1(PGLEFT/AGRSH,GRRAT1 * SHLAG * SHELN(NPP))
           SUPDAY = AMIN1((PGLEFT/AGRSH)/(GRRAT1*SHLAG*SHELN(NPP)),
     +          SWADD1)
           IF (SUPDAY .GE. 1.0) SUPDAY = 1.0
 1600      CONTINUE
C-----------------------------------------------------------------------
C
C     NOW COMPUTE RUNNING AVG RATIO SUPPLY TO DEMAND FOR SHELL GROWTH
C
C-----------------------------------------------------------------------
```

```
            IF (NAGE .EQ. 1) GO TO 1700
            SUPDE(NPP) = (SUPDE(NPP) * (NAGE-1) + SUPDAY)/NAGE
            AVTEM(NPP) = (AVTEM(NPP) * (NAGE-1) + TEMPOD)/NAGE
            GO TO 1800
 1700       CONTINUE
            SUPDE(NPP) = SUPDAY
            AVTEM(NPP) = TEMPOD
 1800       CONTINUE
            WSHDOT = WSHDOT + ADDSHL
            IF (PGLEFT .LT. 1.0E-30) PGLEFT=0.0
            IF (ADDSHL .LT. 1.0E-30) ADDSHL=0.0
            PGLEFT = AMAX1(0.0,(PGLEFT - ADDSHL * AGRSH))
C-----------------------------------------------------------------------
C
C     GROW SHELLS IF GREATER THAN 1 DAY OLD
C-----------------------------------------------------------------------
            SHMINE = 0.0
            SDMAXX = WTSHE(NPP) * THRESH/(100. - THRESH)
            IF ((SHELWT-WTSHM) .LE. 0.0 .OR. SDMAXX .LT. WTSD(NPP)) GO
     +          TO 1900
            SHMINE = XMSHDT * WTSHE(NPP)/(SHELWT - WTSHM)
 1900       CONTINUE
            WTSHE(NPP) = WTSHE(NPP) + ADDSHL - AMAX1(SHMINE,0.0)
 2000       CONTINUE
 2100       CONTINUE
C-----------------------------------------------------------------------
C
C     SET SEEDS BASED ON RATIO OF SUPPLY TO DEMAND OF SHELLS
C     BETWEEN (LAGSD) AND (LAGSD+DTX) PHYSIOLOGICAL DAYS OF AGE
C
C-----------------------------------------------------------------------
      WTABRT = 0.0
            DO 2200 NPP = 1, N-NPODO
            PAGE = PHTIM(N-NPODO+1) - PHTIM(NPP)
            IF (PAGE .LT. LAGSD) GO TO 2200
            IF (PAGE .GE. LAGSD + DTX) GO TO 2200
C-----------------------------------------------------------------------
C
C     PHYSIOL AGE TO SET SEEDS
C
C-----------------------------------------------------------------------
            IF (SUPDE(NPP) .GE. SETMAX) SHRAT = 1.0
            IF (SUPDE(NPP) .LT. SETMAX) SHRAT = SUPDE(NPP)/SETMAX
            SDNO(NPP) = AMIN1(SHRAT,AVTEM(NPP)) * SHELN(NPP) * SDPERP+
     +          SDNO(NPP)
C-----------------------------------------------------------------------
C
C     ABORT SHELLS THAT DO NOT FORM SEED; ABORT (1-SHRAT) FRACTION
C
C-----------------------------------------------------------------------
            WTABR = 0.0
            START = SHELN(NPP)
            SHELN(NPP) = SHELN(NPP) * AMIN1(SHRAT, AVTEM(NPP))
            IF (START .GT. 0.) WTABR = (START-SHELN(NPP))*WTSHE(NPP)/
```

```
     +          START
           WTSHE(NPP) = WTSHE(NPP) - WTABR
           WTABRT = WTABRT + WTABR
 2200      CONTINUE
 2300 CONTINUE
C-----------------------------------------------------------------------
C
C     ADD NEW PODS
C
C-----------------------------------------------------------------------
      IF (N .GT. NDSET .AND. PHTHRS(9) .LT. PHTHRS(10)) ACCAGE = ACCAGE
     +    + DTX*SWFAC/(PHTHRS(10)-PHTHRS(9))
      PODADD = XFRUIT * PODMAX * PMAX * DTX * (1.0 - ACCAGE)* AMIN1
     +     (SWADD1,SWADD2)
      SHELN(N-NPOD0+1) = AMIN1(PODADD,PGLEFT/(GRRAT1*AGRSH))
C-----------------------------------------------------------------------
C     IF (N .GE. NDSET) SHELN(N-NPOD0+1) = 0.0
C-----------------------------------------------------------------------
      WTSHE(N-NPOD0+1) = 0.0
      PGSHEL = WSHDOT * AGRSH
      NNN = N-NPOD0+1
 2400 CONTINUE
C-----------------------------------------------------------------------
C
C     CALCULATE NUMBER OF PODS (INCLUDE SHELLS WHICH DO NOT YET
C     HAVE SEEDS IN THEM AND THOSE THAT DO)
C
C-----------------------------------------------------------------------
      SEEDNO = 0.0
      PODNO = 0.0
      PODMAT = 0.0
      SHLSUM = 0.0
      SDSUM = 0.0
           DO 2600 NPP = 1,N-NPOD0+1
           PAGE = PHTIM(N-NPOD0+1) - PHTIM(NPP)
           SHLSUM = SHLSUM + WTSHE(NPP)
           SDSUM = SDSUM + WTSD(NPP)
           IF (PAGE .LE. LNGPEG) GO TO 2500
           SDMAXX = WTSHE(NPP) * THRESH/(100. - THRESH)
           IF (WTSD(NPP) .GE. 0.90*SDMAXX .OR. PAGE .GT. XMPAGE) PODMAT
     +          = PODMAT + SHELN(NPP)
           PODNO = PODNO + SHELN(NPP)
           SEEDNO = SEEDNO + SDNO(NPP)
 2500      CONTINUE
 2600      CONTINUE
      PODSUM = SHLSUM+SDSUM
      IF (PODNO .GT. 0.) PCTMAT = PODMAT*100./PODNO
 2700 CONTINUE
      RETURN
      END
```

Filename: GENETICS.PN9

```
 02 FLORUNNER, std   02                                  VARIETY 2, MAT. GRP 2
 5.00 12.16 01.00 1.0                                    VARN1,VARNO,VARTH,VARDH
5.00 8.30 0.0 0.0 15.7  8.00 37.6 70.00  54.0   VARTHR(J),J=1,9
 87.00 0.00                                      VARTHR(J),J=10,11
 19.000 17.500 1.7  18.50  100.          SHVAR,SDVAR,SDPDVR,PODVAR,XMPAG
0.423  20.0 245.  1.0   1.384              TRI,SIZELF,SLAVAR,STRCON,PGLF
0.85 1.  0.029  0.03    80.0             XFRT,DETVEG,CNMOB,SHTHIC,THRESH
19.5 11.0 5.5                                    LNGSH,LAGSD,LNGPEG

 21 FL-GB086          02                                VARIETY 10, MAT. GRP 2
 5.00 12.16 01.00 1.0                                    VARN1,VARNO,VARTH,VARDH
5.00 8.30 0.0 0.0 15.7 14.00 37.6 70.00  54.0   VARTHR(J),J=1,9
 87.00  9.50                                     VARTHR(J),J=10,11
 18.000 16.500 1.7  19.00  100.          SHVAR,SDVAR,SDPDVR,PODVAR,XMPAG
0.423  20.0 238.  1.0   1.425              TRI,SIZELF,SLAVAR,STRCON,PGLF
0.75 1.  0.029  0.03    80.0             XFRT,DETVEG,CNMOB,SHTHIC,THRESH
19.5 11.0 5.5                                    LNGSH,LAGSD,LNGPEG

 22 FL-GB087          02                                VARIETY 11, MAT. GRP 2
 5.00 12.16 01.00 1.0                                    VARN1,VARNO,VARTH,VARDH
5.00 8.30 0.0 0.0 15.7  8.00 37.6 70.00  54.0   VARTHR(J),J=1,9
 87.00  4.00                                     VARTHR(J),J=10,11
 19.000 16.500 1.7  19.00  100.          SHVAR,SDVAR,SDPDVR,PODVAR,XMPAG
0.423  20.0 200.  1.0   1.384              TRI,SIZELF,SLAVAR,STRCON,PGLF
0.85 1.  0.029  0.03    80.0             XFRT,DETVEG,CNMOB,SHTHIC,THRESH
19.5 11.0 5.5                                    LNGSH,LAGSD,LNGPEG

 31 FL-PIX83          02                                VARIETY 20, MAT. GRP 2
 5.00 12.16 01.00 1.0                                    VARN1,VARNO,VARTH,VARDH
3.70 5.70 0.0 0.0 15.7  5.00 37.6 70.00  54.0   VARTHR(J),J=1,9
 82.00 10.00                                     VARTHR(J),J=10,11
 19.000 18.000 1.7  19.00  100.          SHVAR,SDVAR,SDPDVR,PODVAR,XMPAG
0.423  20.0 220.  1.0   1.384              TRI,SIZELF,SLAVAR,STRCON,PGLF
0.90 1.  0.029  0.03    80.0             XFRT,DETVEG,CNMOB,SHTHIC,THRESH
19.5  9.0 5.5                                    LNGSH,LAGSD,LNGPEG

 32 FL-PIX85          02                                VARIETY 21, MAT. GRP 2
 5.00 12.16 01.00 1.0                                    VARN1,VARNO,VARTH,VARDH
5.00 8.30 0.0 0.0 15.7 14.00 37.6 70.00  54.0   VARTHR(J),J=1,9
 87.00  2.25                                     VARTHR(J),J=10,11
 19.000 19.000 1.7  19.00  100.          SHVAR,SDVAR,SDPDVR,PODVAR,XMPAG
0.423  20.0 225.  1.0   1.250              TRI,SIZELF,SLAVAR,STRCON,PGLF
0.85 1.  0.029  0.03    80.0             XFRT,DETVEG,CNMOB,SHTHIC,THRESH
19.5 11.0 5.5                                    LNGSH,LAGSD,LNGPEG
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BIOGRAPHICAL SKETCH

Gaétan Bourgeois was born on July 28, 1959, in the city of Saint-Ours located along the Richelieu river in Québec, Canada. He grew up on the dairy farm of his family. In fall 1979, he began an undergraduate program in agriculture with a specialization in plant science at the Macdonald Campus of McGill University in Montréal. He won the Emile A. Lods Prize in 1981 for his achievements in agronomy, and the Cutler Shield in 1982 for the highest aggregate in the final year of agronomy. He graduated with great distinction in spring 1982. In fall 1983, he began his graduate studies in agronomy at the Université Laval in Sainte-Foy, Québec. His interest was the evaluation of alfalfa growth simulation models for potential uses in Québec. He obtained his Master of Science degree in December 1985. In August 1985, he accepted a position with the Agriculture Canada Research Station of Saint-Jean in Québec. He began his doctoral studies in spring 1986 with Dr. Kenneth J. Boote at the University of Florida in Gainesville. Since 1988, he is a member of the Honor Society of Agriculture, Gamma Sigma Delta. He won the Fred H. Hull Agronomy Research and Achievement award in 1989.

Gaétan married Johanne Lacroix from Saint-Simon, Québec, on August 21, 1981, and is the father of two children: his son, Maxime, born on September 11, 1984, in Sainte-Foy, Québec, and his daughter, Isabelle, born on July 26, 1987, in Gainesville, Florida.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Kenneth J. Boote, Chair
Professor of Agronomy

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

James W. Jones
Professor of Agricultural Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Richard D. Berger
Professor of Plant Pathology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Franklin P. Gardner
Professor of Agronomy

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Jerry L. Stimac
Associate Professor of Entomology and Nematology

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December 1989

Jack L. Fry
Dean, College of Agriculture

Dean, Graduate School